EFFECTS OF RACTOPAMINE AND MUSCLE FIBER NUMBER ON SWINE GROWTH PERFORMANCE, CARCASS TRAITS, AND MEAT QUALITY

BY

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DISSERTATION

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ABSTRACT

The objective of this dissertation was to investigate the effects of ractopamine hydrochloride (**RAC**: Paylean®, ELANCO Animal Health, Greenfield, IN) on swine growth performance, carcass traits, meat quality and if its response is influenced by varying muscle fiber number and birth weight. The swine industry is under increasing pressure to maximize efficiency, profitability, and lean meat production. Advances in nutrition, genetics, and general livestock management have enabled producers to increase their efficiency. Increased efficiency is attained through shortening days to harvest (ADG), enhancing feed conversion (G:F), and increasing carcass leanness. One method to increase ADG, G:F, and carcass leanness is through the utilization of RAC. Ractopamine hydrochloride is an orally active β_1 adrenergic agonist that is approved for use in the United States, and is incorporated into the pig's finishing diet for the last 20.4 to 40.8 kg of BW gain. Numerous studies have demonstrated the efficacy of RAC in improving ADG, feed efficiency, carcass weight, dressing percentage, and its negligible effects on meat quality. In this group of studies it was also demonstrated that RAC (10 ppm) was able to increase ADG, G:F, and dressing percentage in pigs that were finished at heavier than normal weight of 147 kg. Ractopamine was also demonstrated to increase HCW, carcass cut yield, and lean cut yield linearly over durations of 7, 14, 21, 28, or 35 d (pooled response of 5.0 and 7.4 ppm). With both aforementioned studies, there were negligible effects on meat quality. Another way to increase productivity in swine production is through decreasing weight variation. Two factors that impact harvest weight variation is birth weight and muscle fiber number. It is commonly recognized that low birth weight correlates with decreased survivability and lower postnatal growth rates. Within this

population of pigs that were investigated, muscle fiber number was not different between birth weight classes of light (0.9 kg), medium (1.2 kg), and heavy (1.5 kg). Muscle fiber diameter however, was increased 14.9 µm in the 5 ppm RAC light birth weight classification compared to the 0 ppm RAC light birth weight classification. When looking at the effects of muscle fiber number (tertile means of 1.3, 1.7, and 2.1 million fibers) on growth performance and meat quality, no trends or patterns were evident.

This dissertation is dedicated to my wonderful wife, Alison, and to my family, without them this would not have been possible.

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Chapter I

REVIEW OF LITERATURE

Introduction

The swine industry is under increasing pressure to maximize efficiency, profitability, and lean meat production. Advances in nutrition, genetics, and general livestock management have enabled producers to increase their efficiency. For example, in 1930 the average sow in the United States farrowed 1.28 litters per year, while in 2002 the average increased to 2.06 litters per sow per year. In 1930 the average number of pigs weaned per litter was six, and in 2002 it increased to 8.8 pigs (Plain and Lawrence, 2003). Currently however, live prices are low and most producers without feed contracts are losing money on pigs, so they are under further pressure to increase productivity. Increased productivity is attained through shortening days to harvest (ADG), enhancing feed conversion (G:F), and increasing carcass leanness. One method to increase ADG, G:F, and carcass leanness is through the utilization of Ractopamine hydrochloride (**RAC**: Paylean, ELANCO Animal Health, Greenfield, IN). Ractopamine hydrochloride is an orally active β_1 adrenergic agonist that is approved for use in the United States, and is incorporated into the pig's finishing diet for the last 20.4 to 40.8 kg of BW gain. Numerous studies have demonstrated the efficacy of RAC in improving ADG, feed efficiency, carcass weight, dressing percentage, and its negligible effects on meat quality (Watkins et al., 1990; Stites et al., 1991; Uttaro et al., 1993; Crome et al., 1996; Carr et al., 2005a; Carr et al., 2005b; Mimbs et al., 2005; Apple et al., 2007; Carr et al., 2009). Response to RAC, however, is

influenced by dosage, duration, and dietary protein concentration (Stites et al., 1991; Williams et al., 1994; Edmonds and Baker, 2010).

Another way to increase productivity in swine production is through decreasing weight variation. This variation in weight is particularly evident in "all-in, all-out" facilities, where the entire finishing barn is marketed at once. The most evident economic cost of this is the sort loss incurred at the slaughter facility. One impact on end weight variation is birth weight. It is commonly recognized that low birth weight correlates with decreased survivability and lower postnatal growth rates (Rehfeldt and Kuhn, 2006). The phenotype of the newborn piglet is the end result of genetic, epigenetic, embryonic and fetal development interactions.

This review will discuss the literature concerning RAC and the effects of birth weight on live animal performance, carcass traits, and meat quality.

Ractopamine

Ractopamine hydrochloride is an orally active β_1-adrenergic agonist that is incorporated into feed rations of finishing swine. In the United States, it is approved for feeding at 5 to 10 ppm for the last 20.4 to 40.8 kg of weight gain. The following review will describe β-adrenergic receptors (**β-AR**), desensitization of β-ARs, RAC's mode of action, and its effects on live animal performance and meat quality.

β-Adrenergic Receptors

Extracellular signals such as growth factors, hormones and neurotransmitters act on membrane bound receptors. One of these membrane bound receptors is the β-AR. The β-AR plays a regulatory role in cardiovascular, respiratory, metabolic, and reproductive function. Three subtypes of β-ARs, β_1, β_2, and β_3, have been identified and sequenced, each with a 65 to 70

% homology in their amino acid structure (Lynch and Ryall, 2008). These receptors are present on most tissues, but their distribution and proportion are varied among organs and species (Mersmann, 1998). The β-AR produces a response when bound by its natural ligands norepinephrine and epinephrine. Over the years scientists have developed synthetic agonistic ligands for the β-AR, which have been heavily utilized in the human and animal pharmaceutical industry. The β-AR is part of a larger class of receptors referred to G protein-coupled receptors (**GPCR**).

G-Protein Coupled Receptor

The G-protein-coupled receptor (GPCR) induces intracellular signals via heterotrimeric G protein complexes composed of α, β, and γ subunits. In the absence of a ligand, the Gα-GDP complex is bound to the Gβγ complex, forming a trimeric complex. Once the agonist binds to this trimeric receptor, the receptor acts as a guanine exchange factor and promotes the exchange of the bound Gα-GDP for Gα-GTP. The Gα-GTP induces a conformation change which releases it from the Gβγ dimer. These two units (Gα-GTP and Gβγ) are now active individual effectors and function in a cascade to produce secondary messengers such as cAMP and IP_3 (McCudden et al., 2005). Just as a note of interest, there are several classes of Gα, and each class has different cellular targets. One class is $G\alpha_s$, which stimulates adenylyl cyclase (**AC**) (Ross and Gilman, 1977). An opposing class is the $G\alpha_i$, which inhibits AC (Smith and Limbird, 1982). The Gβγ has also been demonstrated to regulate kinases. For example, p38 mitogen-activated kinase (MAPK), PI3K-γ, AC isoforms, and proteins with pleckstrin homology (PH) domains are known targets of activated Gβγ (McCudden et al., 2005). The inactivation of the receptor is mediated by an endogenous high affinity GTPase located inside the Gα. This enzyme hydrolyzes the GTP bound to the Gα into Gα-GDP, which then increases the Gα-GDP's affinity for the free Gβγ

subunit. Once these two units are again bound to each other the receptor is inactive and ready for another stimulus. This activation/deactivation cycle can range from milliseconds to seconds depending upon the GPCR (Stryer, 1991).

G-Protein Coupled Receptor Desensitization

GPCRs undergo receptor desensitization due to prolonged exposure to an agonist. Short term desensitization can last from seconds to minutes and involves receptor phosphorylation. The phosphorylation is carried out by the cAMP-independent kinase β-AR kinase1 (βARK), and G protein-coupled receptor kinases (GRK). This phosphorylation leads to binding by β-arrestin and partial uncoupling of G proteins (Johnson, 1998). Prolonging the exposure leads to receptor internalization and after hours of exposure, there is a net loss of receptors via down-regulation and receptor degradation (Ferguson, 2001).

RAC Mode of Action

Post natal muscle growth is through hypertrophy, the enlargement of existing muscle fibers. β-Adrenergic agonist function through three possible general pathways to elicit this hypertrophy: increase in muscle protein synthesis, decrease in protein degradation, or a combination of the previous two (Mersmann, 1998). Bergen et al. (1989) demonstrated that RAC functions in a protein synthetic fashion, and has no effect on protein degradation. They observed in pigs fed 20 ppm RAC, an increase in the fractional protein synthesis rate. Further evidence indicating increased protein synthesis was an increase in RNA synthesis. They demonstrated that RNA concentrations were maintained constant despite the observed muscle hypertrophy, which is indicative of an enhanced rate of RNA synthesis. Allison et al. (1963) states that an increase in RNA indicates an increase in the machinery necessary for protein synthesis, which leads to

increased protein synthesis. This increase in response to RAC is also reflected in the increased RNA/DNA ratio, which is an index of muscle growth (Bergen et al., 1989). With RAC, Bergen et al. (1989) also demonstrated no effect on protein degradation as there was no effect on calcium-dependent protease, cathepsin B or cathepsin H. The effects of β_2-AR agonist, on the other hand, repress protein degradation. Using ^{14}C-amino acid continuous infusion in rats, Reeds et al. (1986) concluded with clenbuterol (β_2-AR agonist) protein fractional breakdown rates were depressed and also ultimately depresses the PGE_2 mediated protein degradation cascade. In regards to gross molecular responses in a study by Shappell et al. (2000), the effects of RAC on C2C12 myoblasts and myotubes were investigated. With an exposure window of 10 minutes to RAC, the myoblasts produced more cAMP per unit of cellular protein than the myotubes. When exposed to RAC for 48 hours, the myoblasts increased cellular number, protein, and DNA content ($P<0.001$). They concluded that the effect of RAC on myoblasts was stimulation of proliferation, due to the unchanged protein:cell, and DNA:cell ratios by treatment. This data was supported by Cook et al. (1995) who demonstrated increased DNA after 72 hour treatment of RAC in porcine satellite cells. Grant et al. (1990) showed a 95% increase in nuclei in chicken satellite cells after 72 hours of RAC treatment. In regards to 5 day old myotubes, Shappell et al. (2000), did not see an increase in protein or DNA after 48 hours treatment. One should note however, that the cells were in a confluent state, and therefore were potentially limited in their response. In contrast, Adeola et al. (1992) observed in the porcine biceps femoris, increases in both myofibrillar protein synthesis ($P<0.05$), and protein breakdown ($P<0.10$) after receiving 20mg/kg RAC for 28 days.

Literature describing the exact molecular mechanism of RAC is lacking, so the following discusses similar β_1-AR and β_2-AR agonist. The old dogma of β-AR signaling has been that

activation of the β-AR starts the $G\alpha_s$ – AC – cAMP cascade, which leads to PKA dependent phosphorylation which then phosphorylates several regulatory peptides. Recently several studies have described several differences in the signaling pathways of the various β-ARs. In mammalian cardiac tissue B_1-AR, stimulation activates the $G\alpha_s$, while β_2-AR evokes both the $G\alpha_i$ and $G\alpha_s$ signaling pathway (Zheng et al., 2004). For example, in the heart β_1-AR is responsible for PKA phosphorylation of several of the calcium handling proteins, such as sarcoplasmic reticulum (SR) membrane proteins, sarcolemmal L-type Ca^{2+} proteins, and ryanodine receptors. Just like in β_1-AR, β_2-AR stimulation will activate the sarcolemmal L-type Ca^{2+} proteins, however, they will not affect the other previously mentioned calcium handling proteins (Xiao and Lakatta, 1993). The free $G\beta\gamma$ generated upon ligand binding to the B-AR have been known to stimulate PI3K which then leads to Ras activation (Marinissen and Gutkind, 2001). Pak et al. (2002) demonstrated a distinct pathway of B_1 in Ras activation compared to the B_2 Ras activation. Other differences in the β_1-AR and β_2-AR is that β_1-AR induced cAMP can broadcast throughout the cell, while β_2-AR induced cAMP is confined to subsarcolemmal microdomains (Xiao et al., 1999). Morisco et al. (2000) demonstrated specific stimulation of β_1-AR can cause hypertrophy in cultured neonatal rat cardiac myocytes through the PI3K/AKT pathway. Chesley et al. (2000) demonstrated that β_2-AR stimulation does not promote cardiac muscle cell hypertrophy, but rather protects cells from assaulting factors such as enhanced β_1 pathway, apoptosis, and hypoxia.

Effects of Ractopamine Hydrochloride on Live Animal Performance

The effects of RAC on live animal performance are well documented. Apple et al. (2007) performed a meta analysis summarizing the effects of RAC from studies ranging from 1990 to 2005 and 0, 5, 10, and 20 ppm. The compilation of data indicated an approximate

increase ($P < 0.001$) in ADG with 5 ppm of 12 %. With 5 ppm RAC, Stites et al. (1991) showed an increase in ADG of 6.4 % and Armstrong et al. (2004) showed an increase in ADG of 25.9 %. Meta analysis showed increases in ADG with 10 and 20 ppm RAC at 11.2 % (Apple et al., 2007). See et al. (2004) showed an 7 % increase in ADG with 10 ppm RAC. With the meta analysis, only 20 ppm was able to statistically decrease ADFI to 4.2 %. Individually with 10 ppm though, Carr et al. (2005b) and Mimbs et al. (2005) saw decreases in ADFI (8.8 % and 7.6 % respectively). At doses of 5 and 10 ppm G:F ratios became statistically greater (10 % improvement) and 20 ppm (14.3 % improvement) (Apple et al., 2007). The improvement, however, spanned from 3.2 % (Gu et al., 1991) to 26.7 % (Armstrong et al., 2004).

Effects of Ractopamine Hydrochloride on Carcass traits

Ractopamine's effects on carcass characteristics are also well acknowledged. Continuing with the meta analysis by Apple et al. (2007), they demonstrated an approximate 2 kg increase in HCW with 5, 10, and 20 ppm RAC. A linear improvement, with 0, 5, 10, and 20 ppm RAC (79.2 80.7, 82.1, and 83.3 kg respectively) was shown by Stites et al. (1991). The meta analysis however, was not able to detect a significant RAC effect in dressing percentage (Apple et al., 2007). Individual studies however were able to detect improvements in dressing percentage. With 10 and 20 ppm at 34 d durations, Armstrong et al. (2004) was able to detect an approximate 1.15 percentage unit increase in dressing percentage. Stites et al. (1991) also saw a linear increase, with 0, 5, 10, and 20 ppm RAC, in dressing percentage (74.2, 74.4, 74.9 and 76.2 % respectively). Ractopamine is also demonstrated to improve carcass leanness. Estimated fat-free lean yield was increased by 0.9 % (5 ppm RAC) 1.3 % (10 ppm RAC) and 2.4 % (20 ppm RAC; Apple et al. 2007). Schinckel et al. (2003a,b), however, suggests that the prediction equations my under estimate RAC's effect on carcass leanness. Regarding back fat depth, there have been

mixed results in the literature. Some previous research has found (Carr et al., 2005a) no difference (P >0.05) in first rib, 10th rib, last rib, or last lumbar fat depths, and Armstrong et al. (2004) also found no difference (P >0.05) in 10th rib back fat. However, other research has demonstrated reductions in fat depth (Williams et al., 1994; Crome et al., 1996).

Effects of Ractopamine Hydrochloride on Meat Quality

Overall RAC has negligible on meat quality. Ultimate pH, firmness, on average, is not affected, nor are there appreciable differences with 5, 10, or 20 ppm RAC (Apple et al. 2007). Pork color is one of the most important quality characteristics affecting consumers' perception of point of sale freshness (Brewer and Mckeith, 1999). Ractopamine, 5, 10, and 20 ppm, also has minimal effects on subjective and objective color (Apple et al., 2007). In regards to tenderness, Warner-Bratzler shear force values are mixed in regards to the literature. Apple et al. (2007) meta analysis did detect a difference of 0.42 kg at 10 ppm, and 0.33 kg at 20 ppm. However, trained sensory taste panelists were unable to detect differences in studies by Stoller et al. (2003) and Stites et al. (1994).

Effects of Birth Weight

Postnatal muscle growth can only occur through hypertrophy of existing muscle fibers, and not through the creation of additional muscle fiber (Rehfeldt et al., 2000). Differences in fiber numbers may impart the variation in body weight that producers are experiencing (Dwyer et al., 1993). Accompanying birth weight variation is body weight variation at finishing. Variation at this stage in the swine industry also has major financial impacts. Financial loss results from increases in farm labor due to sorting and decreases in revenue from packer sort loss.

Intrauterine Growth Restriction

Programmed prenatal effects on postnatal growth performance often do not manifest till late in the finishing period. One of the factors implicated in prenatal programming is uterine capacity and associated intrauterine growth restriction (**IUGR**). Intrauterine growth restriction can be defined as impaired growth and development of the mammalian embryo or fetus during pregnancy. Several studies summarized by Wu et al. (2006) suggest the intrauterine environment may play an important role in prenatal programming. In domestic animals when the embryo from a genetically larger mother was transferred to a recipient dam with a lower uterine capacity, IUGR was present. On the contrary, when an embryo from a genetically smaller mother was transferred to a dam with greater uterine capacity, fetal growth was enhanced. For example, Allen et al. (2002) transferred Thoroughbred embryos into Ponies (Tb-in-P) and transferred Pony embryos into Thoroughbred horses (P-in-Tb). Compared to the control (P-in-P) the P-in-Tb foals were 13.9 kg heavier. The Tb-in-P foals compared to controls (Tb-in-Tb) were 20.1 kg lighter. Natural IUGR can be seen in dams with multi-fetal pregnancies. Even though the total placental weight may be greater in multi-fetal animals, the placental mass per fetus is reduced, resulting in relative placental insufficiency (Redmer et al., 2004). Relative placental insufficiency is evident in ewes, heifers, cows, and mares when multi-fetal pregnancy occurs (Wu et al., 2006). Of the domestic animals, swine display the most instances of natural IUGR. Most evident IUGR in swine is location effect within the uterine horns. Fetuses near both ends of the uterus are generally larger, 5 to 10 %, than those in the middle of the horn, and 10 to 15 % larger at the ovarian end compared to the cervical end. This is particularly evident when fetus number is greater than five in each horn (Perry and Rowell, 1969). In the more severe instances of IUGR runts develop. They, however, can be present at

any location with the uterine horn, and are more affected by placental size. In runts the small intestine, liver, and skeletal mass are disproportionally smaller than the largest littermates (Widdowson, 1971).

Mechanisms of IUGR

Impaired placental development is one mechanism of IUGR. The placenta is responsible for transportation of nutrients, exchange of gases, and products of fetal metabolism. Placental development is necessary for fetal growth and development (Gootwine, 2004). Gootwine (2004) demonstrated that increased expression of placental anabolic compounds like prolactin and placental lactogen enhances fetal growth in sheep. Decreased placental blood flow is also a contributing factor to IUGR. Increases in placental blood flow are necessary to meet the metabolic needs of the developing fetus (Reynolds et al., 2005). During pregnancy reduced placental proliferation in the fetal trophectoderm and decreased expression of angiogenic factors underlie attenuated uteroplacental blood flow and resulting IUGR. In heat stress or multiple fetal induced IUGR decreased placental angiogenesis results, which reduces uteroplacental blood flow as well as reduced placental and fetal growth (Wallace et al., 2002). According to Wootton et al. (1977) in sows at gestation day 77 to 110 there are correlations between placental weight and placental blood flow, between placental weight and fetal weight. They also state that in comparison with its litter mates the runt fetal pig is associated with a small placenta and low rate of placental blood flow. This is also around the time frame of the secondary muscle fiber formation (Fig. 3). In addition to the compromised blood flow, leucine transport was reduced in the small porcine fetus compared to average size fetuses. Asami-Miyagishi et al. (2004) demonstrated the effects of peroxisome proliferator-activated receptor (PPAR) γ on rat fetuses *in utero*. When PPARγ was administered between gestational day 9 and 11, they noticed an

decrease in the fetal mortality. The control dams had fetal mortalities of 15% and the treated dams had fetal mortalities of 7.2%. PPARγ is necessary for placental development, as demonstrated with PPARγ null mice which result in impaired trophoblast differentiation and placental vascularization. Asami-Miyagishi et al. (2004) speculated that additional PPARγ in wild type rats enhanced placental development, thus allowing for decreased IUGR. Unfortunately however, treated rats were not carried out full term, so treatment effects on birth weights or weaning weights are unknown.

Fetal Programming

Phenotypic potential manifested as muscle growth of the piglet can be influenced by prenatal fetal programming. According to Foxcroft et al. (2004) prenatal fetal programming predetermines the growth potential of the piglet. Prenatal programming is influenced by many factors including nutrition, health status, birth weight, and muscle fiber number. Muscle fiber number has a large impact on postnatal muscle growth. There is growing evidence that maternal or fetal nutritional status can alter the epigenetic state of the fetal genome and gene expression of imprinted genes such as Igf2 and H19. Silencing of genes expression is related to the methylation of DNA, and other proteins. Interestingly, Igf2 is paternally expressed, but it is maternally silent, whereas H19 is paternally silent and preferentially expressed from the maternal allele (Doherty et al., 2000). Epigenetic alterations, such as stable alterations of gene expression through covalent modifications of DNA and core histones in early embryos, may be carried forward to subsequent developmental stages (Waterland and Jirtle, 2004). Two mechanisms mediating epigenetic effects are DNA methylation (occurring in the 5′-positions of cytosine residues within CpG dinucleotides throughout the mammalian genome) and histone modification (Jaenisch and Bird, 2003). The CpG methylation can regulate gene expression by modulating

the binding of methyl-sensitive DNA-binding proteins, thereby affecting regional chromatin conformation. Histone modifications can alter the positioning of histone-DNA interactions and the affinity of histone binding to DNA, thereby affecting gene expression (Jaenisch and Bird, 2003). The DNA and protein methylation are catalyzed by specific DNA and protein methyltransferases, with S-adenosylmethionine (**SAM**) being the methyl donor in these reactions (Jaenisch and Bird, 2003). S-adenosylmethionine is synthesized from methionine and ATP by methionine adenosyltransferase, and its placental concentration is greatest when placental growth is most rapid. The synthesis of creatine is quantitatively the most important pathway for SAM utilization and thus is a major regulator of methyl donor availability in the body (Stead et al., 2001). When the diet is deficient in cysteine/taurine or contains excess methionine, an increase in cysteine/taurine synthesis from methionine consumes a large amount of SAM. One-carbon-unit metabolism, which depends on serine, glycine, histidine, choline, and B vitamins, including folate, vitamin B12, and vitamin B6, in addition to methionine, plays an important role in regulating the availability of SAM. Thus, DNA methylation and histone modifications may be altered by the overall availability of amino acids and micronutrients (Oommen et al., 2005). Epigenetics may provide a molecular mechanism for the impact of maternal nutrition on the fetal programming of postnatal growth performance and disease susceptibility (Wu et al., 2006).

Growth Efficiency

One of the more important organs in postnatal growth is the small intestine. It is the terminal site for digestion and absorption of a majority of nutrients. Increased nutrient absorption allows for greater protein disposition. Protein disposition in growing animals accounts for approximately 15% of total energy expenditure (Wu, 1998). Wang et al. (2005) elucidated a connection between IUGR (0.60 kg v. 1.02 kg birth weight) and abnormal

gastrointestinal morphologies and gastrointestinal dysfunction. Compared with high birth weight lambs (4.8 kg), IUGR newborn lambs (2.3 kg) grew slower within the first 2 weeks and exhibited lower rates of efficiency in energy utilization for protein and fat disposition. They also had lower intramuscular concentrations of DNA and lower rates of postnatal growth (ADG 337.0 g/d) (Greenwood et al., 2000). Quiniou et al. (2002) also demonstrated that lower piglet birth weight is associated with lower ADG during the suckling, nursing, and growing-finishing periods. Wolter et al. (2002) reported heavy compared to light birth weight pigs (1.83 vs 1.32 kg) were approximately 13% heavier at weaning. Gondret et al. (2005) also used 2 birth weight categories (1.91 vs 0.97 kg) and reported an approximate 35% reduction in weaning weight of the light birth weight pigs compared to the heavy birth weight pigs. When evaluating the growth performance of the same pigs he reported that the light birth weight pigs grew slower from weaning to market weight (787 vs 816 g/day) which resulted in an additional 12 days to reach harvest weight.

Muscle Characteristics and Meat Quality

Wigmore and Stickland (1983) concluded that large porcine fetuses generally had more muscle fiber numbers in their semitendinosus muscle than smaller fetuses. At 64 days' gestation there was a 17 % difference in total muscle (semitendionous) number in light versus heavy birthweight. They further concluded that most of the variation was due to differences in number of secondary fibers that formed around each primary fiber. In the larger fetuses, the primary fibers were larger, which would support more secondary fibers, and also the larger fetuses contained more DNA in their muscles. Rehfeldt and Kuhn (2006) also reported that when harvested at a common age (183 d), light birth weight pigs (0.94 kg) had trending (P = 0.09) lower percentage of lean meat (54.8 vs. 56.5 %) and lighter HCW (84.2 vs. 92.5 kg) in

comparison to heavier birth weight pigs (1.80 kg). When looking at pigs harvested at similar adult weights (approximately 104 kg), light birth weight pigs (1.27 vs. 1.76 kg) had larger muscle fiber diameters and lighter muscle carcasses. In addition, at slaughter the semitendinosus muscle of piglets with the lowest birth weights had 9.3 % fewer glycolytic fibers compared with littermates with the heaviest birth weight (Bee, 2004). Gondret et al. (2006) compared several histological and meat quality traits in light versus heavy (1.05 vs. 1.89 kg) birth weight pigs. They found that light birth weight pigs had 12 % greater cross sectional fiber area and 7.7 % lighter Longissimus muscle weight. In regards to meat quality, light birth weight pigs had higher L* values (55.7 vs. 53.9) and tougher tenderness values (4.0 vs. 4.7; 0 most tough, 10 most tender) through a trained taste panel. Berard et al. (2008), however, did not see differences in shear force between light (1.41 kg) and heavy (1.96 kg) birth weight pigs.

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Chapter 2

RACTOPAMINE HYDROCHLORIDE (PAYLEAN®) RESPONSE IN HEAVY WEIGHT FINISHING PIGS

Abstract

The objective of this study was to investigate the effects of feeding diets with 10 ppm of ractopamine HCL (RAC) to heavy weight pigs (final BW of 147 kg). Few studies, address the effects of RAC on performance and carcass traits at the finishing weights presented in this study. This study was carried out as a randomized complete block design with a 2 x 2 factorial arrangement of treatments: 1) gender (barrow or gilt); and 2) RAC inclusion (0 ppm or 10 ppm), with a total of 128 pigs. Pigs were randomly assigned to pens of 4 and starting weight was approximately 115 kg. After 28 d on test pigs were harvested, and a subset of pigs, totaling 64 pigs (2 pigs/pen), were selected for carcass characteristics and meat quality analysis. There were no gender × RAC interactions ($P > 0.10$). Final farm BW was increased ($P = 0.003$) 3.3 kg, overall ADG was increased ($P = 0.009$) 11.0%, and overall G:F was increased ($P < 0.001$) 12.9% with RAC. The HCW was increased ($P < 0.001$) by 3.9 kg with RAC, and dressing percentage was increased ($P = 0.001$) by 0.98%. In the subset selected for carcass characteristics (n = 64), there was a trend of increasing ($P = 0.08$) lean cut yield by 0.61 %. Ultimate pH was increased ($P < 0.0001$) by 0.08 units, and drip loss was decreased ($P = 0.011$) 1.28 % with RAC. Feeding diets with 10 ppm of RAC to pigs with ending BW of approximately 147 kg proved efficacious in improving BW, ADG, G:F, HCW, and dressing percentage without adversely affecting meat quality traits.

Introduction

Ractopamine hydrochloride (**RAC**) is an orally active beta-adrenergic agonist that is incorporated into feed rations of finishing swine. Numerous studies have demonstrated the efficacy of RAC in improving ADG, feed efficiency, carcass weight, dressing percentage, and its negligible effects on meat quality (Watkins et al., 1990; Stites et al., 1991; Uttaro et al., 1993; Crome et al., 1996; Carr et al., 2005b; Mimbs et al., 2005; Apple et al., 2007; Carr et al., 2009). Effective April of 2006, the Food and Drug Administration approved the feeding 5 to 10 ppm RAC to finishing swine for the last 20.4 to 40.8 kg of gain. The previous label, valid from December of 1999 to April, 2006, approved the use of RAC in finishing swine weighing from 68 to 109 kg BW. This new label opens the possibility of feeding RAC to swine at heavier final farm weights. Feeding swine to heavier final farm weights may offer economic benefits such as increased kilograms of pork produced per sow per year as well as increased packer production efficiency (Crome et al., 1996). Few studies have addressed the efficacy of feeding RAC to swine with final farm weights of 130 to 140 kg. Crome et al. (1996) compared the growth and carcass response of two weight groups of finishing swine (107 and 125 kg final farm weight). They demonstrated that the heavier weight group still responded favorably to 10 and 20 ppm RAC in regards to growth performance and carcass traits. A component of a recent study by Carr et al. (2009) fed 5 and 20 ppm of RAC with 16% CP to a final farm wt of approximately 133 kg. With 20 ppm of RAC, Carr et al. (2009) demonstrated a 3.6 cm^2 increase in LEA, 0.35 unit increase in muscle score, and an increase of 0.46 kg on a ham trimmed wholesale cut (IMPS-401).

This study investigated the effects of 10 ppm RAC on finishing performance, carcass characteristics and meat quality of pigs harvested at approximately 147 kg.

Materials and Methods

Experimental Design

The protocol for this study was approved by the Institutional Animal Care and Use Committee of the University of Illinois. The study was carried out as a randomized complete block design with a 2 x 2 factorial arrangement of treatments: 1) gender (barrow or gilt); and 2) RAC inclusion (0 ppm or 10 ppm). Pigs were the progeny of PIC 337 x C22 matings. The experiment was carried out over four blocks. Each block had two replicates, comprised of four pens per replicate (1 per gender × RAC subclass), resulting in a total of 32 pens across four blocks. Each pen housed four pigs resulting in 128 pigs across four blocks.

Allotment, Treatments, and Growth Performance Measurements

Pigs were allotted to pens to create average pen weights of approximately 107 kg. Once pigs were allotted, they were allowed to acclimate to their new pen for 7 d. During acclimation, pigs had *ad libitum* access to Control diet, Table 2.1. The 28-d test phase commenced at the end of the 7-d acclimation phase. While on test, pigs were given *ad libitum* access to their assigned diet, Table 1. Pigs were weighed weekly during the 28-d trial period to determine ADG. Feeder weights and feed additions to each feeder were recorded to determine ADFI (as-fed basis) and G:F.

Carcass and Meat Quality Measurements

On the final day of test (d 28), pigs were weighed off test in the morning, and were housed in their test pen with access to food and water until they were loaded and transported to either the University of Illinois Meat Science Laboratory, or the commercial harvest facility. The two pigs closest to the pen mean BW at d 28 were selected for carcass characteristics and meat quality analysis, and these pigs were transported to the University of Illinois Meat Science Laboratory on the morning of harvest. Meanwhile, the remaining two pigs per pen were sent to a commercial harvest facility the morning of harvest, where HCW and last rib fat were collected for subsequent percent lean calculation (NPPC, 2001).

A subset of pigs, totaling 64 pigs (2 pigs/pen) was utilized to collect detailed measurements on carcass characteristics and fresh pork quality traits. Briefly, pigs were transported the morning of harvest, electrically stunned, exsanguinated, scalded, dehaired, decapitated, eviscerated, split, inspected, and placed immediately into a 4°C chill cooler. Approximate time from stun to cooler was 45 min. Of the two pigs selected from each pen, one was randomly selected for pH decline and temperature decline measurement. Pigs that were selected for pH decline were measured at 45 min, 1.5 h, 3 h, 4.5 h, and 6 h with a MPI pH-meter (Meat Probes Inc, Topeka, Kansas) in the Longissimus muscle of the carcass's right side. The first time point was collected at approximately the 13th rib and subsequent time points proceeded anteriorly by one rib increments. Temperature decline from 45 min to approximately 20 h was recorded with a temperature recorder (Monitor Company, Modesto, CA) inserted into the right side Longissimus posterior to the last rib.

After chilling for approximately 20 h, the left side was ribbed at the 10th rib and allowed to bloom for approximately 15 min. Last-rib, 10th-rib fat depths, and 10th-rib LEA were measured. Meat quality traits measured at the 10th rib included subjective color and marbling scores (NPPC, 1999), subjective firmness (NPPC, 1991), Japanese color score, and objective color utilizing a Minolta CR-300 with a D65 light source and a 0° observer (Minolta Camera Company, Osaka, Japan). A section of longissimus was dissected out posterior to the 10th rib, faced off and chops were cut. Chop collection starting from the tenth rib included: 1.3 cm thick chop for drip loss; 2.54 cm thick chop for proximate composition analysis; and 2.54 cm thick chop aged for 14 d for Warner Bratzler shear force determination. Drip loss was used to evaluate water-holding capacity. Drip loss chops were weighed, suspended from a fish hook in a Whirl-pak bag for approximately 24 h at 4 °C and then reweighed. Results were reported on a percent loss basis. Proximate composition on homogenized samples was determined with oven drying to determine moisture content, and extraction with an azeotropic chloroform and methanol mixture to determine extractable lipid, as described by (Novakofski et al., 1989).

The right side of each carcass was further processed to primals and boneless subprimals. Weights of primals, boneless subprimals and intermediate cuts were collected. All weights represent the weights of the respective cuts from a single side of the carcass. The number associated with the cut description shown in tables is the Institutional Meat Purchase Specification (IMPS, 1996) or the North American Meat Processors Association (NAMP, 1997) number most closely associated with actual cut specifications. Primal, subprimal and boneless yields are expressed as a percentage of HCW and were calculated using the equation: % of HCW = ([2 ×actual cut weight]/ HCW) × 100. Lean cut yields were calculated by using the formula: ((boneless ham (inside + outside + knuckle + light butt) + Canadian back + boneless tenderloin + boneless sirloin + boneless Boston butt + boneless picnic) x 2) / HCW. The carcass cut yield is the lean cut yield plus the trimmed belly. The lean and fat trimmings generated from boneless cut fabrication were collected, ground, and moisture and extractable lipid proximate composition was determined as previously described.

Statistical Analysis

Data were analyzed using the PROC MIXED procedure in SAS (SAS, 2000). The model included the effects of block, gender, RAC inclusion, and gender by RAC inclusion interaction. The random effect of replicate within block was also included in the model for live animal performance. Pen was used as the experimental unit for the analysis of live performance, and pig was the experimental unit used in the carcass trial. There were no gender × RAC interactions for any of the criteria measured, and thus, only the main effects of RAC will be discussed.

Results and Discussion

Finishing Performance

Finishing performance is presented in Table 2.2. Live animal performance data is separated into five time periods: overall, wk 1, 2, 3, and 4. During wk 1 of the RAC feeding period, there was a trending increase ($P = 0.08$) in ADG, but there were not any differences in BW, ADFI, or G:F. During wk 2, RAC

increased ($P < 0.01$) BW, ADG, and G:F. The same response continued during wk 3, with an additional response of decreased ($P = 0.03$) ADFI. During wk 4 however, the only difference between treatments was BW ($P = 0.003$). Final farm BW was increased ($P = 0.003$) by 3.3 kg in the RAC treatment. Inclusion of RAC increased ($P = 0.009$) overall ADG by 11.0%, corresponding with an overall increase ($P < 0.001$) in G:F of 12.9%. These overall results are similar with results seen in lighter weight pigs (Stites et al., 1991; Armstrong et al., 2004).

Carcass Traits

Carcass traits are presented in Table 2.3 for all 128 pigs. The HCW was increased ($P < 0.001$) by 3.9 kg with RAC, and dressing percentage was increased ($P = 0.001$) to 76.13 % from 75.34 %. Similar improvements in HCW and dressing percentage were seen in pigs approaching a similar final weight as targeted in this study (Crome et al., 1996). Watkins et al. (1990) and Carr et al. (2005b) also saw improvement in dressing percentage with 10 ppm RAC. Last rib fat depth however, was not affected, which is similar to Carr et al. (2005b). The combination of a heavier HCW and equal last rib fat depth, resulted in a greater amount ($P < 0.001$) of calculated fat free lean.

Effects of RAC on BW and carcass traits in the selected subset (2 pigs/pen closest to the pen BW mean) are presented in Table 2.4. Final farm weight was increased ($P = 0.007$) by 4.1 kg and HCW was increased ($P = 0.001$) by 4.3 kg with RAC. Dressing percentage was increased ($P = 0.02$) by 0.79 %. Tenth rib and last rib fat depth were unaffected by RAC (Table 4). Previous reports of 10 ppm RAC not affecting tenth rib back fat have been reported (Stites et al., 1991; Armstrong et al., 2004). Inclusion of RAC also increased ($P = 0.004$) loin eye area by 3.19 cm^2.

Carcass Cutting Yields

Effects of RAC on wholesale cut weights as a percentage of HCW are presented in Table 2.5. Fresh ham (IMPS-401) percentage ($P = 0.03$) was increased by 0.48 % with RAC. This is similar with Carr et al. (2005a), which saw similar increases in fresh ham (IMPS-401) weight percentage, but with 20

ppm RAC. Neck bone (IMPS-421) percentage, however, was decreased (P = 0.006) 0.21 % with RAC. Assuming equal skeletal weights, a decrease in neck bone percentage with the RAC treatment could be due to the resulting increase in HCW with RAC. Shoulder (IMPS-403), jowl, belly (IMPS-408), skin-on loin (IMPS 410), and spareribs (IMPS-416) percentages were unaffected (P > 0.16) by RAC.

Effect of RAC on trimmed wholesale weights as a percentage of HCW is presented in Table 2.6. Fresh ham (IMPS-401C), picnic (IMPS-405), Boston butt (IMPS-406), skin-on belly (IMPS-409B), and loin (IMPS-410) percentages were not affected (P > 0.51) by RAC. However, when feeding 20 ppm as in Uttatro et al. (1993), and holding HCW equal, increases in trimmed weights of loin, ham, and belly were observed.

Effect of RAC on boneless cut weight as a percentage of HCW is presented in Table 2.7. Fresh ham outside (IMPS-402E) percentage was increased (P = 0.003) by 0.25 %, and tenderloin (IMPS-415A) percentage was trending (P = 0.09) towards a 0.04 % increase. Fresh ham inside (IMPS-402F), light butt, knuckle, picnic (IMPS-405A) Boston (IMPS-406A), cellar trimmed butt (IMPS-407), Canadian back (IMPS-414), and sirloin percentages were not affected (P > 0.122) by RAC. Carr et al. (2005a), however, saw increases in Boston (IMPS-406A), Canadian back (IMPS-414), and sirloin weight percentages.

Effect of RAC on trim composition is presented in Table 2.8. Lean cut yield values were trending towards an increase (P = 0.08) of 0.61 %, while carcass cut yield was unaffected (P = 0.132; Table 8). Trimmings (IMPS-418) weight percentage was unaffected by RAC, however, the percent moisture was increased (P = 0.05) by 1.15 % and percent extractable lipid was decreased (P=0.01) by 1.86 % by RAC, resulting in an increase (P=0.01) in calculated trimmings fat free lean percentage of 1.89 %. These results coincide with Carr et al. (Carr et al., 2005a).

Meat Quality

Effects of RAC on meat quality were mixed, as presented in Table 2.9. Both NPPC and Japanese color scores and marbling scores were unaffected by RAC, as seen with other studies (Armstrong et al.,

2004; Carr et al., 2005a). Firmness scores, however, were increased (P = 0.004) 0.54 units with RAC. Objective color was affected by RAC treatment. L* values were trending with a decrease (P = 0.06) (less white) of 1.91 units, a* were decreased (P < 0.0001) (less red) 1.73 units, and b* were decreased (P = 0.001) (less yellow) 1.36 units. The same trend with a* and b* was seen with 10 ppm (Carr et al., 2005a) and 20 ppm RAC (Uttaro et al., 1993). Ultimate pH was increased (P < 0.0001) by 0.08 units, and drip loss was decreased (P = 0.01) 1.28 % with RAC. Temperature decline from 45 min to 20 h, and pH decline from 45 min to 6 h were not different at any time point (data not presented), which agrees with Carr et al. (2005b). Other meat quality traits such as cook loss, shear force, loin percent moisture and loin extractable lipid, were also not affected.

Implications

Feeding 10 ppm of RAC to pigs with ending BW of approximately 147 kg proves efficacious in regards to improving BW, ADG, G:F, carcass weight, dressing percentage and calculated kg of fat free lean. Dietary RAC inclusion of 10 ppm also had minimal impacts on meat quality.

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Tables

Table 2.1 Ingredient composition and calculated nutrient composition of diet[1,2]

Ingredients	Control
Corn, kg	660.57
Soybean meal, 48% CP, kg	215.83
Fat, liquid, kg	9.08
Dicalcium phosphate, kg	8.63
Calcium carbonate, kg	6.85
Salt, kg	3.63
Swine Micro 4, kg[1]	1.82
L-Lysine, kg	1.59
Nutrients	
ME, Kcal/kg	3246.3
CP, %	16.3
Lysine, %	1.0
Available lysine, %	0.9
Available phosphorus, %	0.2
Calcium, %	0.6

[1]The RAC 10 ppm diet contained 0.45 kg of Paylean 9G

[2] Provided the following nutrients per kilogram of diet: vitamins: A, 1137.5 IU; D3, 227.5 IU; E, 5 IU; riboflavin, 0.8 mg; pantothenic acid (as d-calcium pantothenate), 2.9 mg; niacin, 5.5 mg; B12, 5.0 µg; choline (as choline chloride), 3.0 µg; menadione (as menadione sodium bisulfite complex), 0.15 mg. Minerals: iodine (as ethylenediamine dihydroiodide), 0.4 mg; copper (as copper sulfate), 10.0 mg; manganese (as manganous oxido), 32.0 mg; iron (as ferrous sulfate), 80 mg; zinc (as zinc oxide), 90 mg; selenium (as sodium selenite), 0.3 mg.

Table 2.2. Effect of 10 ppm RAC on live animal performance during finishing

	RAC, ppm			
	0	10	SEM	*P* value
Number of pens	16	16	-	-
Initial BW, kg	115.5	115.4	0.76	0.873
Final farm BW, kg	145.9	149.2	0.97	0.003
Overall ADG, kg	1.09	1.21	0.04	0.009
Overall ADFI, kg	3.54	3.42	0.08	0.164
Overall G:F, kg	0.31	0.35	0.01	< 0.001
Week 1				
BW, kg	123.3	124.2	0.85	0.292
ADG, kg	1.12	1.27	0.08	0.084
ADFI, kg	3.07	3.07	0.14	0.991
G:F, kg	0.38	0.42	0.03	0.170
Week 2				
BW, kg	131.6	133.9	0.83	0.013
ADG, kg	1.18	1.38	0.06	0.003
ADFI, kg	3.59	3.59	0.09	0.961
G:F, kg	0.33	0.38	0.01	< 0.001
Week 3				
BW, kg	138.7	142.3	0.84	< 0.001
ADG, kg	1.03	1.20	0.08	0.044
ADFI, kg	3.79	3.55	0.10	0.032
G:F, kg	0.27	0.34	0.02	0.007
Week 4				
BW, kg	145.9	149.2	0.97	0.003
ADG, kg	1.02	0.99	0.09	0.677
ADFI, kg	3.71	3.49	0.15	0.153
G:F, kg	0.28	0.29	0.03	0.839

Table 2.3. Effect of 10 ppm RAC on carcass traits from entire population

	RAC, ppm			
	0	10	SEM	*P* value
Number of pens	16	16	-	-
HCW, kg	109.1	113.0	0.76	< 0.001
Last rib fat depth, cm	2.51	2.47	0.03	0.530
Dressing percentage	75.06	76.04	0.24	0.001
Fat free lean[1], kg	56.0	58.2	0.40	< 0.001
Fat free lean[2], %	51.39	51.51	0.25	0.624

[1] As calculated from the National Pork Producers Council formula: pounds fat free lean = 23.568 + (0.503 x HCW) – (21.348 x last rib fat depth), English units were used in the equation then converted back to kg

[2] As calculated: fat free lean percentage = kg fat free lean / HCW

Table 2.4. Effect of 10 ppm RAC on BW and carcass traits in pigs selected for carcass cutouts

	RAC, ppm			
	0	10	SEM	*P* value
Number of pigs	32	32	-	-
Final farm wt, kg	144.5	148.6	1.45	0.007
HCW, kg	108.8	113.1	1.18	0.001
Dressing percentage	75.34	76.13	0.31	0.026
10th rib fat, cm	2.22	2.17	0.05	0.703
Last rib fat, cm	2.19	2.27	0.04	0.479
LEA[1], cm^2	52.23	55.42	1.05	0.004

[1]Loin eye area, measured at the 10^{th} rib

Table 2.5. Effect of 10 ppm RAC on wholesale cut weights (kg) and weights as a percentage of HCW[1]

	RAC, ppm			
	0	10	SEM	*P* value
Number of pigs	32	32	-	-
401 Fresh ham wt, kg	13.00	13.78	0.19	< 0.001
401 Fresh ham, %	23.89	24.37	0.22	0.038
403 Shoulder wt, kg	14.98	15.30	0.23	0.164
403 Shoulder, %	27.53	27.07	0.32	0.169
421 Neck bone wt, kg	1.20	1.30	0.04	0.090
421 Neck bone, %	2.20	1.99	0.07	0.011
Jowl wt, kg	2.01	2.06	0.09	0.535
Jowl, %	3.69	3.66	0.17	0.842
408 Belly wt, kg	10.17	10.48	0.17	0.077
408 Belly, %	18.68	18.54	0.23	0.533
410 Loin (skin on) wt, kg	13.99	14.46	0.21	0.037
410 Loin (skin on), %	25.70	25.56	0.22	0.541
416 Spareribs wt, kg	2.12	2.18	0.05	0.240
416 Spareribs, %	3.89	3.86	0.09	0.730

[1]Wholesale cut weights are indentified by the Institutional Meat Purchase Specification (IMPS, 1996)

Table 2.6. Effect of 10 ppm RAC on trimmed wholesale cut weights (kg) and weights as a percentage of HCW[1]

	RAC, ppm			
	0	10	SEM	*P* value
Number of pigs	32	32	-	-
401C Fresh ham wt, kg	10.99	11.55	0.27	0.048
401C Fresh ham, %	20.19	20.42	0.41	0.579
405 Picnic wt, kg	5.75	5.91	0.10	0.130
405 Picnic, %	10.57	10.46	0.16	0.513
406 Boston butt wt, kg	4.06	4.27	0.08	0.026
406 Boston butt, %	7.47	7.55	0.13	0.558
409B Belly (skin on) wt, kg	6.41	6.62	0.16	0.212
409B Belly (skin on), %	11.78	11.68	0.24	0.704
410 Loin wt, kg	11.07	11.45	0.16	0.029
410 Loin, %	20.34	20.26	0.20	0.680

[1]Wholesale cut weights are indentified by the Institutional Meat Purchase Specification (IMPS, 1996)

Table 2.7. Effect of RAC on boneless cut weights (kg) and weights as a percentage of HCW[1]

	RAC, ppm			
	0	10	SEM	*P* value
Number of pigs	32	32	-	-
402F Fresh ham, inside wt, kg	1.85	1.98	0.05	0.011
402F Fresh ham, inside, %	3.39	3.50	0.07	0.124
402E Fresh ham, outside wt, kg	2.68	2.93	0.06	< 0.001
402E Fresh ham, outside, %	4.93	5.18	0.08	0.003
Light Butt wt, kg	0.35	0.38	0.02	0.115
Light Butt, %	0.64	0.67	0.03	0.388
Knuckle wt, kg	1.45	1.53	0.03	0.003
Knuckle, %	2.66	2.71	0.05	0.269
405A Picnic wt, kg	4.60	4.78	0.09	0.063
405A Picnic, %	8.46	8.46	0.14	0.987
406A Boston wt, kg	3.68	3.89	0.08	0.012
406A Boston, %	6.77	6.89	0.13	0.357
407 Cellar trimmed butt wt, kg	2.20	2.30	0.07	0.158
407 Cellar trimmed butt, %	4.04	4.06	0.11	0.806
414 Canadian back wt, kg	3.90	4.04	0.08	0.071
414 Canadian back, %	7.16	7.14	0.10	0.871
415A Tenderloin wt, kg	0.48	0.52	0.01	0.003
415A Tenderloin, %	0.88	0.92	0.02	0.099
Sirloin wt, kg	1.00	1.05	0.29	0.100
Sirloin, %	1.83	1.85	0.05	0.713

[1]Wholesale cut weights are indentified by the Institutional Meat Purchase Specification (IMPS, 1996)

Table 2.8. Effect of 10 ppm RAC on lean cut yield, carcass cut yield, and trim composition

	RAC, ppm			
	0	10	SEM	*P* value
Number of pigs	32	32	-	-
Lean cut yield[1], %	36.71	37.32	0.35	0.083
Carcass cut yield[2], %	48.49	49.01	0.34	0.137
418 Trimmings, kg	13.53	14.26	0.23	0.002
418 Trimmings, % of HCW	24.86	25.23	0.30	0.220
Proximate composition				
Trimmings, moisture %	58.81	59.96	0.57	0.051
Trimmings, extractable lipid %	25.18	23.32	0.72	0.013
Trimmings, fat-free lean[3], %	74.79	76.68	0.73	0.019

[1]Lean cut yield = ((boneless ham (inside + outside + knuckle + light butt) + Canadian back + boneless tenderloin + boneless sirloin + boneless Boston butt + boneless picnic) x 2) / HCW

[2]Carcass cut yield = ((boneless ham (inside + outside + knuckle + light butt) + Canadian back + boneless tenderloin + boneless sirloin + boneless Boston butt + boneless picnic + trimmed belly) x 2) / HCW

[3]Calculated value = (100 – Trimmings, extractable lipid)

Table 2.9. Effect of 10 ppm RAC on meat quality

	RAC, ppm			
	0	10	SEM	*P* value
Number of pigs	32	32	-	-
Color score (NPPC, 1999)[1]	2.75	2.59	0.17	0.362
Marbling score (NPPC, 1999)[2]	1.56	1.50	0.17	0.728
Firmness score (NPPC, 1991)[3]	1.96	2.50	0.18	0.004
Japanese color score	2.96	2.75	0.18	0.249
Minolta L*[4]	52.75	50.84	1.00	0.062
Minolta a*[5]	9.02	7.29	0.39	< 0.001
Minolta b*[6]	5.65	4.29	0.39	0.001
Ultimate pH	5.48	5.56	0.02	< 0.001
Drip loss, %	5.59	4.31	0.49	0.010
Cook Loss, %	25.05	24.98	0.90	0.934
Shear, kg	2.97	3.10	0.11	0.247
Loin moisture, %	74.13	74.11	0.14	0.922
Loin extractable lipid, %	2.61	2.64	0.18	0.881

[1] National Pork Producers Council (NPPC) color scale (1 to 5): 1=pale pinkish to white; 5= dark purplish red.
[2] NPPC marbling scale (1 to 5): percentage fat in the loin.
[3] NPPC firmness scale (1 to 5): 1= very soft; 5= very firm.
[4] L*, greater value indicates a lighter color.
[5] a*, greater value indicates a redder color.
[6] b*, greater value indicates a more yellow color.

Chapter 3

COMPARISON OF VARYING DOSES AND DURATIONS OF RACTOPAMINE HYDROCHLORIDE (PAYLEAN®) ON LATE FINISHING PIG CARCASS CHARACTERISTICS AND MEAT QUALITY

Abstract

The study objective was to investigate the effect of various doses and durations of ractopamine hydrochloride (**RAC**; Paylean®, ELANCO Animal Health, Greenfield, IN) on pig HCW, cutting yields, and meat quality. Late finishing pigs (approximately 93 kg) were allotted to 12 treatments 35 d prior to market. Treatments consisted of: negative control (**NEG**; 13.1 % CP, 0.64 TID Lys), positive control (**POS**; 17.8 % CP, 0.94 TID Lys); two RAC doses and durations of 5 ppm (4.5 g/ton), or 7.4 ppm (6.75 g/ton) and 7, 14, 21, 28, or 35 d. Ractopamine duration diets were fed with NEG until incorporation of RAC when diet was switched to POS to comply with label requirements. At harvest, five pigs closest to the average pen wt (240 pigs total) were selected for analysis. Differences in responses between 5 ppm and 7.4 ppm were not significant, so data were pooled. All comparisons between NEG and POS diets were not significant. Hot carcass weight was increased ($P < 0.001$) 2.52 kg from the NEG weight of 88.2 kg and increased ($P < 0.001$) 2.34 kg from the POS weight of 88.4 kg. Hot carcass weight also increased linearly ($P < 0.001$) as duration increased. Indicators of carcass leanness increased with RAC compared to NEG. For example, fat free lean percentage increased ($P = 0.004$) to 55.9 % from 54.78 %, carcass cut yield increased ($P < 0.001$) to 51.82 % from 50.58 %, as well as ($P = 0.003$) boneless lean cut yield to 37.91 % from 36.74 %. Subjective marbling score decreased ($P < 0.001$) 0.5 units from the NEG value of 3.0. Subjective color values or tenderness aging curves from RAC were not significantly different from NEG or POS. Overall, RAC at both levels of 5 ppm and 7.4 ppm had greater responses in carcass weight and cut yield than NEG, and had minimal affect on meat quality.

Introduction

Today's swine industry is under increasing pressure to maximize efficiency, profitability, and lean meat production. Currently in the United States, a method to increase growth and feed efficiency is the incorporation of ractopamine hydrochloride (**RAC**: Paylean, ELANCO Animal Health, Greenfield, IN) into the finishing diet for the last 20.4 to 40.8 kg of BW gain. Structurally RAC is similar to catecholamines and has a high affinity to the β-adrenergic receptor (Mills, 2002). Binding of RAC to β-adrenergic receptors increases production of cyclic adenosine monophosphate, which acts as messenger in activating cellular mechanisms responsible for improvements in growth performance (Mersmann, 1998). Numerous studies have demonstrated the efficacy of RAC in improving ADG, feed efficiency, carcass weight, dressing percentage, and its negligible effects on meat quality (Watkins et al., 1990; Stites et al., 1991; Uttaro et al., 1993; Crome et al., 1996; Carr et al., 2005a; Carr et al., 2005b; Mimbs et al., 2005; Apple et al., 2007; Carr et al., 2009). Response to RAC, however, is influenced by dosage, duration, and dietary protein concentration (Stites et al., 1991; Williams et al., 1994; Edmonds and Baker, 2010). In regards to duration, Williams et al. (1994) demonstrated that maximum improvement in growth performance with 44.7 mg/d RAC was achieved within 21 d. Dunshea et al. (1993) further demonstrated, with 20 ppm RAC, improvement in ADG from 21 d to 28 d, thereafter the benefit was not as pronounced. This lack of continued response may be due to either a down regulation or desensitization of β-adrenergic receptors (Moody et al., 2000).

In addition to duration, levels of dietary protein affect RAC response (Dunshea et al., 1993). Dunshea et al. (1993) demonstrated as dietary protein content increased from 8.5 % to 22.2 % (in approximate increments of 2.7 %), RAC elicited a linear increase in ADG and protein deposition. To obtain the increase in growth performance, RAC United States label requirements state that it must be incorporated into diets containing at least 16% CP. This 16 % CP, however, is higher than the more commercially representative NRC crude protein requirement of 13% for finishing pigs (National Research Council, 1998). In regards to non-RAC treated pigs, increases in dietary protein concentration do not

affect carcass traits (Webster et al., 2007). Webster et al. (2007) compared the effects of varying dietary crude protein, from 13.2 % (0.60 % total Lys) to 24.5 % (1.40 % total Lys) on carcass traits. From this study they were not able to demonstrate a linear response from dietary protein in any of the carcass traits that they measured.

This study had two objectives: investigate the effects of 5.0 and 7.4 ppm RAC inclusion on carcass traits, cutting yield, and meat quality, and investigate RAC's effect, on the aforementioned criteria, over 5 different durations of 0, 7, 14, 21, 28, and 35 d. Previous research has not been completed comparing RAC response in a commercial feed program where pigs not on RAC would receive the NRC crude protein level and pigs on RAC are reformulated with greater than 16% CP to meet United States label requirements.

Materials and Methods

Experimental Design and Treatments

Samples were obtained from a federally inspected harvesting facility.

Terminal cross bred pigs from industry representative genetics were randomly assigned to single gender pens, approximately 20 pigs per pen. Initial allotting weight was 93kg. Blocks were made of single gender replicates which consisted of 12 pens. Block one consisted of two barrow replicates and one gilt replicate. Block two consisted of two gilt replicates, one barrow replicate, one incomplete gilt replicate and one incomplete barrow replicate. Two control diets were utilized in this study, negative (**NEG**; 13% CP, 0.64 TID Lys), and positive (**POS**; 17.8 % CP, 0.94 TID Lys). The RAC treatments, 5.0 and 7.4 ppm RAC, were formulated with the POS diet, and was comprised of 0, 7, 14, 21, 28 or 35 d durations. The 35-day duration groups received treatment feed at allotment. The 28 day duration groups began receiving treatment feed 7 days later. The 21 day duration groups began receiving treatment feed 14 days later. The 14 day duration groups began receiving treatment feed 21 days later. The 7 day duration groups began receiving treatment feed 28 days later. All pigs receiving RAC treatment received

the NEG control diet prior to receiving the RAC treatment feed. Along with a NEG treatment for 35 days, there was a POS treatment for 35 days. All pens within the same block were harvested on the same day. From two replicates in each block (one male, one female), individual pig weights were collected. From these four replicates, at d 35, 5 pigs from each pen (closest to the pen average) were selected for detailed carcass and meat quality analysis, for a total of 240 pigs.

Product Collection and Carcass Data

Pigs were harvested per industry standards. Hot carcass weight was measured before entering the coolers. Fat depth, muscle depth, and percent lean were measured using the Animal Ultrasound System (AUS) (Animal Ultrasound Services and CO, INC.). Following a 24 hr chill, carcasses were fabricated and right side primals, consisting of the shoulder, loin, belly and ham, were transported back the University of Illinois Meat Science Lab for processing. Weights of primals, boneless cuts, and all intermediate cuts were collected. All presented weights represent the weights of the respective cuts from a single side of the carcass. The number associated with the cut description shown in tables is the Institutional Meat Purchase Specification (IMPS, 1996), North American Meat Processors Association (NAMP, 1997) number of the cut most closely associated with actual cut specifications. Primals, boneless cuts, and all intermediate cuts yields are expressed as a percentage of HCW and were calculated using the equation: % of HCW = ([2 ×actual cut weight]/ HCW) × 100. Lean cut yields were calculated from the collected weights with the formula: ((boneless ham (inside + outside + knuckle + light butt) + Canadian back + tenderloin + sirloin + boneless Boston butt + boneless picnic) x 2) / HCW. The carcass cut yield is the lean cut yield plus the trimmed belly.

Meat Quality

Meat quality was assessed on Canadian backs (IMPS-414) generated from the aforementioned cut yields. Meat quality traits, measured at approximately the 10^{th} rib, included subjective color and marbling scores (NPPC, 1999), subjective firmness (NPPC, 1991), Japanese color score, and objective color

utilizing a Minolta CR-300 with a D65 light source and a 0° observer (Minolta Camera Company, Osaka, Japan. Chop collection starting from the tenth rib included: a 1.3-cm-thick chop for drip loss; a 2.54-cm-thick chop for proximate composition analysis; four 2.54-cm-thick chops for Warner Bratzler shear force determination. Chops for shear force determination were aged for 3, 7, 14, and 21 days. Proximate composition of moisture was determined with oven drying, and extractable lipid from loin chops were determined by extraction with an azeotropic chloroform and methanol mixture as described by (Novakofski et al., 1989). To assess fresh meat quality of the ham, pH and objective color were measured on the lightest portion of the inside surface on the semimembranosus.

Statistical Analysis

A one-way analysis of variance (the MIXED procedure, SAS Institute, Cary NC) (SAS, 2000) was used to evaluate the effects of dose and duration of RAC, and dietary crude protein level on various outcome variables. The pig served as the experimental unit. The only fixed effect in the statistical model was treatment. Block (harvest date), replicate within block, and the block by replicate interaction were included as random effects. If any of these random effects were not statistically significant ($P > 0.05$), they were dropped from the model. As mentioned previously, only single gender replicates were utilized in this study. Therefore, gender was not included in the model, however, the variation due to gender was accounted for by including replicate in the model. Differences due to dosage were not significant ($P > 0.05$), so data were pooled. Given seven treatment groups, six orthogonal contrasts were used to evaluate the objectives of this study: Contrast 1, NEG vs. POS; contrast 2, NEG control vs. RAC; contrast 3, POS control vs. RAC; contrast 4, linear effects of duration within RAC; contrast 5, quadratic effects of duration within RAC; contrast 6, POS control vs. 35 d RAC duration.

Results and Discussion

Carcass Traits

There were not any significant differences between the main effects of dose (5.0 and 7.4 ppm RAC; $P > 0.100$), therefore data was pooled. Ractopamine duration treatments were confounded with two diets (NEG and POS), however, differences between the two diets were not significant ($P > 0.060$). Effects on carcass traits are presented in Tables 3.1 and 3.2. The RAC treatment increased ($P < 0.001$) HCW by 2.5 kg from the NEG weight of 88.2 kg and 2.3 kg from the POS weight of 88.4 kg. Hot carcass weight also increased linearly ($P < 0.001$) over the durations, and at 35 d the HCW was 3.5 kg heavier ($P < 0.001$) than POS. Similar increases in HCW, approximately 4 kg, were seen with both light weight (107 kg) and heavy weight (125 kg) pigs (Crome et al., 1996). Dressing percentage was increased ($P = 0.008$) to 74.89 % from the NEG dressing percentage of 73.98 %. Muscle depth was increased ($P = 0.005$) by 0.49 cm with RAC from the NEG depth of 6.41 cm. Back fat depth was unaffected ($P = 0.326$) by the overall RAC treatment, however, there was a linear decrease ($P = 0.033$) in fat depth as the RAC duration increased. Regarding back fat depth, there have been mixed results in the literature. Carr et al. (2005a) found no difference ($P >0.05$) in first rib, 10^{th} rib, last rib, or last lumbar fat depths and Armstrong et al. (2004) also found no difference ($P >0.05$) in 10^{th} rib back fat. However, other research has demonstrated reductions in fat depth (Williams et al., 1994; Crome et al., 1996). With RAC compared to NEG, calculated fat free lean percentage was increased ($P = 0.004$) to 55.9 % from 54.78 %. At 35 d, compared to POS, RAC had increased ($P = 0.020$) calculated fat free lean percentage (56.11 % vs. 55.19 %). Increases in carcass leanness are consistent with previous literature (Bark et al., 1992; Carr et al., 2009).

Carcass Cutting Yields

Effects of RAC dosage and duration on cutting yields are presented in Tables 3.1 and 3.2. Compared to NEG, carcass cut yield increased ($P < 0.001$) to 51.8 % from 50.58 %, as well as ($P =$

0.003) lean cut yield to 37.9 % from 36.74 %. Compared to POS (37.15 %), RAC lean cut yield was trending greater (P = 0.054) at 37.9 %. Compared to POS, 35 d RAC had increased carcass cut yield (P = 0.010; 52.32 % vs. 51.24 %), and lean cut yield (P = 0.003; 38.62 % vs. 37.15 %). Both carcass cut yield (P = 0.005) and lean cut yield (P = 0.002) increased linearly as the RAC duration increased. .

Effects of RAC dosage and duration on wholesale cut weights are presented in Tables 3.3 and 3.4. Fresh ham (IMPS-401) weight was increased (P = 0.008) 0.3 kg from NEG weight of 10.37 kg and increased (P = 0.003) 0.4 kg from POS weight of 10.33. Fresh ham weight increased linearly (P = 0.002) as duration increased, and at 35 d it was 0.6 kg heavier (P = 0.0003) than POS. Shoulder (IMPS-403) weight was increased (P = 0.04) 0.3 kg from POS weight of 10.29 kg. Shoulder weight also increased linearly (P = 0.002) as the durations increased, and by 35 d, RAC was 0.4 kg heavier (P = 0.03) than POS. Belly (IMPS-408) weights increased (P = 0.04) 0.3 kg over the NEG weight of 8.70 kg. This is similar with Carr et al. (2005a), which saw similar increases in wholesale weights with 10 and 20 ppm RAC.

Effect of RAC and RAC duration on trimmed wholesale weights and as a percentage of HCW is presented in Tables 3.5 and 3.6. Fresh ham weight (IMPS-401C) was increased (P = 0.001) 0.41 kg from the NEG weight of 8.93 kg, and increased (P = 0.001) 0.42 kg from the POS weight of 9.92 kg. The weight was also increased (P < 0.001) 0.66 kg and percent of HCW increased (P = 0.024) to 20.84 % with 35 d duration compared to POS (20.18 %). There was also a positive linear (P = 0.007) duration response. Stites et al. (1991) saw similar increases in trimmed ham weights. Picnic (IMPS-405) weight was increased (P = 0.023) 0.16 kg from the POS weight of 4.64 kg. As RAC durations increased, picnic weight increased (P = 0.007), and at 35 d the weight was 0.24 kg heavier (P = 0.005). Boston butt (IMPS-406) weight was increased, trending, (P = 0.051) 0.11 kg from the CON weight 3.84 kg, and was increased (P = 0.001) 0.19 kg from the POS weight of 3.76 kg. Boston weight increased (P < 0.001) linearly over time, and at 35 d it was 0.31 kg heavier (P < 0.001) than POS and was a greater proportion (P = 0.016) of HCW. Skin-on belly (IMPS-409B) weights were not affected (P > 0.122). Loin (IMPS-

410) weight was increased ($P < 0.001$) 0.52 kg from the CON weight of 9.69 kg, and increased ($P = 0.033$) 0.29 kg from the POS weight of 9.92 kg. Loin percentage of HCW was increased ($P = 0.030$) to 22.5% from the NEG percentage of 21.98 %. Loin weight and percentage of HCW both increased linearly ($P < 0.001$) with increasing durations, and at 35 d loin weight was increased 0.71 kg from POS and percentage of HCW was increased to 23.16 % from POS percentage of HCW, 22.45 %. Uttatro et al. (1993), feeding 20 ppm, saw increases in trimmed weights of loin, ham, and belly.

Effect of RAC and RAC duration on boneless cut weights and as a percentage of HCW is presented in Tables 3.7 and 3.8. Fresh ham inside (IMPS-402F) weight increased linearly ($P = 0.010$) over the test period. Fresh ham outside (IMPS-402E) weight was increased ($P = 0.048$) 0.10 kg from the CON weight of 2.22 kg, and increased ($P = 0.007$) 0.14 kg from the POS weight of 2.18 kg. Outside weight and percentage of HCW increased linearly ($P< 0.034$), and weight at 35d was increased 0.23 kg from POS, and percentage of HCW increased to 5.24 % from POS of 4.93 %. Knuckle weight was increased 0.11 kg from NEG weight of 1.11kg, and percentage of HCW was increased to 2.70 % compared to NEG of 2.51%. Light butt weight increased ($P = 0.023$) 0.04 kg from POS, and percentage HCW increased ($P = 0.047$) to 0.50 % from POS, 0.38%. There was also a positive quadratic response in both weight at 35 d and percentage of HCW ($P < 0.044$). Picnic (IMPS-405A) weight was increased ($P = 0.022$) 0.13 kg from NEG weight of 3.37 kg, and increased ($P = 0.009$) 0.15 kg from POS weight of 3.35 kg. Picnic weight increased linearly ($P = 0.004$) over the durations, and at 35 d it was 0.21 kg heavier ($P = 0.001$) than POS. Boston butt (IMPS-406) weight was increased ($P = 0.004$) 0.11 kg from NEG weight of 3.85, and increased ($P < 0.001$) 0.56 kg from POS of 3.40 kg. Boston butt percentage of HCW was increased ($P = 0.013$) to 8.70 % from POS of 7.69 %. Boston butt weight increased linearly ($P < 0.001$) over the duration, and at 35 d it was 0.31 kg heavier ($P < 0.001$) than POS and percentage of HCW was increased ($P = 0.003$) to 8.05 % from POS, 7.69%. Cellar trimmed butt (IMPS-407) weight was increased ($P = 0.010$) 0.09 kg from POS weight of 1.61 kg. Cellar trimmed butt also increased linearly ($P = 0.001$) over duration. At 35 d, weight was increased ($P = 0.001$) 0.15 kg and percentage of HCW was

increased (P = 0.045) to 3.83 % from POS of 3.65 %. Clear plate was decreased (P < 0.001) 0.12 kg from NEG weight of 0.98 kg. Clear plate as a percentage of HCW was decreased (P < 0.001) to 1.91 % from NEG of 2.22 %, and was lower (P = 0.030) than POS of 2.06 %. Percentage of HCW weight was linearly decreasing (P = 0.008), and at 35 d it was 1.82 % of HCW from POS. Canadian back (IMPS-414) weight was increased (P < 0.001) 0.31 kg from NEG weight of 3.10 kg, and increased (P = 0.028) 0.15 kg from POS weight of 3.26 kg. Percentage of HCW was increased (P = 0.001) to 7.53 % from the NEG of 7.03 %. Both weight and percentage of HCW increased linearly (P < 0.001), and 35 d weight was increased (P < 0.001) 0.32 kg from POS, and percentage of HCW was increased (P = 0.013) to 7.79 % from POS of 7.38 %. Tenderloin (IMPS-415A) weight was increased (P < 0.001) 0.05 kg from NEG of 0.05 kg, and increased (P = 0.001) 0.04 kg from POS of 0.41 kg. Percentage of HCW was also increased (P < 0.010) to 1.0% compared to NEG (0.90 %) and POS (0.93 %). Weight and percentage of HCW also increased linearly (P < 0.001) over test duration. At 35 d weight was 0.07 kg heavier (P < 0.001) and percentage of HCW was greater (P = 0.001) than POS. Sirloin weight was increased (P = 0.024) 0.07 kg compared to NEG weight of 0.79 kg. Both weight and percentage of HCW also increased linearly (P < 0.001).

Meat Quality

Effect of RAC and RAC duration on meat quality is presented in Tables 3.9 and 3.10. Within the loin, objective colors changed while duration increased. Color become darker linearly (P = 0.025), as indicated by lower Minolta L* values. This is in contradiction with Armstrong et al. (2004) who saw no difference in Minolta L* values with dosages of 5 and 10 ppm RAC. Minolta a* and b* values, although not significantly different (P > 0.067) from either controls, did decrease linearly (P < 0.005) indicating a less red color (a*) and less yellow color (b*) as duration increased. Previous literature has reported significant decreases in a* and b* values with 10 ppm and 20 ppm dosages (Uttaro et al., 1993; Carr et al., 2005a). These subtle changes, however, even though statistically significant, may not be visually noticeable (Apple et al., 2007). Subjective marbling score decreased (P < 0.001) 0.5 units from the NEG

value of 3.0. Extractable lipid decreased ($P < 0.027$) to 1.8 % compared to NEG (2.25 %) and POS (2.13 %). There was also a linear decrease ($P = 0.005$) in extractable lipid over duration. Our trends in marbling scores and extractable lipid are in contradiction with the current literature. Apple et al. (2007) meta analysis indicates no impact of RAC on marbling scores, and Carr et al. (2005a,b) saw no differences in extractable lipid. Fresh ham ultimate pH ($P = 0.024$) increased linearly in duration as did Minolta L* ($P = 0.001$), and Minolta b* ($P = 0.013$). Minolta b* was also lowered ($P = 0.030$) 0.95 units from NEG of 8.47.

Implications

Overall, RAC had greater responses in carcass weight and cut yield than NEG, and had minimal affect on meat quality. Given the significant linear effects, and absence of quadratic responses (expect for Light butt weight and subjective color score) we could speculate our treatments did not induce desensitization.

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Tables

Table 3.1. Effect of Ractopamine on carcass traits

	Control						
	NEG[1]	POS[2]	RAC[3]	NEG v. POS[4]	NEG v. RAC[5]	POS v. RAC[6]	Pooled SEM[7]
HCW, kg	88.2	88.4	90.7	0.837	< 0.001	< 0.001	0.675
Dressing percentage	73.98	74.44	74.89	0.328	0.008	0.174	0.502
Fat depth[8], cm	1.71	1.65	1.63	0.578	0.326	0.814	0.093
Loin depth[8], cm	6.41	6.57	6.90	0.485	0.005	0.063	0.228
Calculated Fat free lean[8], %	54.78	55.19	55.86	0.368	0.004	0.083	0.400
Lean cut yield[9], %	36.74	37.15	37.91	0.155	0.001	0.096	0.419
Carcass cut yield[10], %	50.58	51.24	51.82	0.434	0.003	0.054	0.559

[1] Negative control, 13 % CP
[2] Positive control, 17 % CP
[3] Pooled Ractopamine 5.0 ppm and 7.4 ppm data, average of 7, 14, 21, 28, and 35 d durations
[4] Contrast *P* value of negative control versus positive control
[5] Contrast *P* value of negative control versus Ractopamine response averaged across durations
[6] Contrast *P* value of positive control versus Ractopamine response averaged across durations
[7] Largest observed
[8] Measured with Animal Ultrasound System (Animal Ultrasound Services and CO, INC.)
[9] Lean cut yield = ((boneless ham (inside + outside + knuckle + light butt) + Canadian back + boneless tenderloin + boneless sirloin + boneless Boston butt + boneless picnic) x 2) / HCW
[10] Carcass cut yield = ((boneless ham (inside + outside + knuckle + light butt) + Canadian back + boneless tenderloin + boneless sirloin + boneless Boston butt + boneless picnic + trimmed belly) x 2) / HCW

Table 3.2. Effect of Ractopamine duration on carcass traits[1]

		Ractopamine[2]								
Duration	POS[3]	7 d	14 d	21 d	28 d	35 d	POS v. 35d[4]	Linear[5]	Quadratic[6]	Pooled SEM[7]
HCW, kg	88.4	89.1	90.6	90.1	91.9	91.9	< 0.001	< 0.001	0.662	0.675
Dressing percentage	74.44	74.88	74.50	74.60	75.26	75.26	0.396	0.732	0.869	0.502
Fat Depth, cm	1.65	1.64	1.72	1.68	1.60	1.53	0.174	0.033	0.098	0.093
Muscle Depth, cm	6.57	6.87	6.88	6.83	6.96	6.94	0.070	0.544	0.803	0.228
Calculated Fat free lean[8], %	55.19	55.70	55.53	55.56	55.98	56.11	0.020	0.084	0.251	0.400
Carcass cut yield, %	51.24	51.37	51.66	51.79	52.00	52.32	0.010	0.005	0.888	0.419
Lean cut yield, %	37.15	37.29	37.88	37.84	38.16	38.62	0.003	0.002	0.932	0.559

[1]Wholesale cut weights are indentified by the Institutional Meat Purchase Specification (IMPS, 1996)
[2] Pooled Ractopamine 5.0 ppm and 7.4 ppm data
[3] Positive control, 17 % CP, 35 d
[4] Contrast *P* value of positive control versus 35 d value
[5] Contrast *P* value of linear Ractopamine response
[6] Contrast *P* value of quadratic Ractopamine response
[7] Largest observed
[8] Measured with Animal Ultrasound System (Animal Ultrasound Services and CO, INC.)

Table 3.3. Effect of Ractopamine on wholesale cut weights (kg) and weights as a percentage of HCW[1]

	Control						
	NEG[2]	POS[3]	RAC[4]	NEG v. POS[5]	NEG v. RAC[6]	POS v. RAC[7]	Pooled SEM[8]
401 Fresh ham wt, kg	10.37	10.33	10.71	0.826	0.008	0.003	0.144
401 Fresh ham wt, % of HCW	23.51	23.37	23.61	0.677	0.688	0.336	0.269
403 Shoulder wt, kg	10.46	10.29	10.58	0.322	0.303	0.019	0.114
403 Shoulder, % of HCW	23.70	23.30	23.35	0.188	0.109	0.871	0.215
408 Belly wt, kg	8.70	8.94	9.03	0.273	0.036	0.512	0.224
408 Belly, % of HCW	19.69	20.23	19.93	0.193	0.480	0.292	0.513
416 Spareribs wt, kg	1.58	1.64	1.63	0.259	0.177	0.874	0.058
416 Spareribs, % of HCW	3.58	3.70	3.61	0.216	0.869	0.129	0.132
421 Neck bone wt, kg	0.94	0.96	0.94	0.722	0.810	0.473	0.065
421 Neck bone, % of HCW	2.14	2.16	2.08	0.741	0.221	0.096	0.149

[1]Wholesale cut weights are indentified by the Institutional Meat Purchase Specification (IMPS, 1996)
[2] Negative control, 13 % CP
[3] Positive control, 17 % CP
[4] Pooled Ractopamine 5.0 ppm and 7.4 ppm data, average of 7, 14, 21, 28, and 35 d durations
[5] Contrast *P* value of negative control versus positive control
[6] Contrast *P* value of negative control versus Ractopamine response averaged across durations
[7] Contrast P value of positive control versus Ractopamine response averaged across durations
[8] Largest observed

Table 3.4. Effect of RAC dosage on wholesale cut weights (kg) and weights as a percentage of HCW[1]

		Ractopamine[2]								
Duration	POS[3]	7 d	14 d	21 d	28 d	35 d	POS v. 35d[4]	Linear[5]	Quadratic[6]	Pooled SEM[7]
401 Fresh ham wt, kg	10.33	10.43	10.80	10.68	10.77	10.88	< 0.001	0.002	0.361	0.144
401 Fresh ham wt, % of HCW	23.37	23.42	23.79	23.73	23.43	23.68	0.283	0.754	0.456	0.269
403 Shoulder wt, kg	10.29	10.42	10.51	10.51	10.73	10.73	0.002	0.002	0.873	0.114
403 Shoulder, % of HCW	23.30	23.39	23.30	23.34	23.33	23.34	0.887	0.872	0.781	0.215
408 Belly wt, kg	8.94	8.94	9.07	8.94	9.15	9.07	0.450	0.300	0.828	0.224
408 Belly, % of HCW	20.23	20.08	20.03	19.86	19.91	19.72	0.134	0.178	0.925	0.513
416 Spareribs wt, kg	1.64	1.59	1.63	1.64	1.62	1.68	0.277	0.016	0.957	0.058
416 Spareribs, % of HCW	3.70	3.57	3.62	3.64	3.52	3.65	0.492	0.650	0.992	0.132
421 Neck bone wt, kg	0.96	0.93	0.94	0.94	0.95	0.93	0.391	0.731	0.370	0.065
421 Neck bone, % of HCW	2.16	2.16	2.09	2.08	2.10	2.06	0.030	0.238	0.393	0.149

[1]Wholesale cut weights are indentified by the Institutional Meat Purchase Specification (IMPS, 1996)
[2] Pooled Ractopamine 5.0 ppm and 7.4 ppm data
[3] Positive control, 17 % CP, 35 d
[4] Contrast *P* value of positive control versus 35 d value
[5] Contrast *P* value of linear Ractopamine response
[6] Contrast *P* value of quadratic Ractopamine response
[7] Largest observed

Table 3.5. Effect of Ractopamine on trimmed wholesale cut weights (kg) and weights as a percentage of HCW[1]

	Control						
	NEG[2]	POS[3]	RAC[4]	NEG v. POS[5]	NEG v. RAC[6]	POS v. RAC[7]	Pooled SEM[8]
401C Fresh ham wt, kg	8.93	8.92	9.34	0.930	0.001	< 0.001	0.150
401C Fresh ham, % of HCW	20.26	20.18	20.59	0.812	0.170	0.091	0.286
405 Picnic wt, kg	4.67	4.64	4.80	0.758	0.061	0.023	0.072
405 Picnic, % of HCW	10.59	10.50	10.60	0.648	0.922	0.477	0.136
406A Boston wt, kg	3.84	3.76	3.95	0.270	0.051	0.001	0.054
406A Boston, % of HCW	8.72	8.52	8.72	0.203	0.948	0.076	0.113
409B Belly (skin on) wt, kg	6.12	6.22	6.31	0.583	0.173	0.517	0.202
409B Belly (skin on), % of HCW	13.84	14.09	13.92	0.525	0.880	0.476	0.462
410 Loin wt, kg	9.69	9.92	10.21	0.212	0.000	0.033	0.310
410 Loin, % of HCW	21.98	22.45	22.54	0.183	0.030	0.676	0.626

[1]Wholesale cut weights are indentified by the Institutional Meat Purchase Specification (IMPS, 1996)
[2] Negative control, 13 % CP
[3] Positive control, 17 % CP
[4] Pooled Ractopamine 5.0 ppm and 7.4 ppm data, average of 7, 14, 21, 28, and 35 d durations
[5] Contrast *P* value of negative control versus positive control
[6] Contrast *P* value of negative control versus Ractopamine response averaged across durations
[7] Contrast P value of positive control versus Ractopamine response averaged across durations
[8] Largest observed

Table 3.6. Effect of Ractopamine duration on trimmed wholesale cut weights (kg) and weights as a percentage of HCW[1]

		Ractopamine[3]								
Duration	POS[2]	7 d	14 d	21d	28 d	35 d	POS v. 35d[4]	Linear[5]	Quadratic[6]	Pooled SEM[7]
401C Fresh ham wt, kg	8.92	9.03	9.40	9.29	9.43	9.58	< 0.001	< 0.001	0.534	0.150
401C Fresh ham, % of HCW	20.18	20.28	20.73	20.65	20.51	20.84	0.024	0.094	0.631	0.286
405 Picnic wt, kg	4.64	4.72	4.78	4.76	4.89	4.88	0.005	0.007	0.981	0.072
405 Picnic, % of HCW	10.50	10.59	10.62	10.55	10.63	10.61	0.505	0.874	0.917	0.136
406A Boston wt, kg	3.76	3.87	3.91	3.92	4.02	4.07	< 0.001	< 0.001	0.453	0.054
406A Boston, % of HCW	8.52	8.69	8.66	8.71	8.73	8.85	0.016	0.124	0.373	0.113
409B Belly (skin on) wt, kg	6.22	6.29	6.30	6.24	6.39	6.31	0.578	0.665	0.950	0.202
409B Belly (skin on), % of HCW	14.09	14.13	13.92	13.86	13.90	13.71	0.207	0.122	0.835	0.462
410 Loin wt, kg	9.92	9.88	10.08	10.09	10.44	10.63	< 0.001	< 0.001	0.356	0.310
410 Loin, % of HCW	22.45	22.18	22.38	22.39	22.71	23.16	0.026	< 0.001	0.246	0.626

[1]Wholesale cut weights are indentified by the Institutional Meat Purchase Specification (IMPS, 1996)
[2] Pooled Ractopamine 5.0 ppm and 7.4 ppm data
[3] Positive control, 17 % CP, 35 d
[4] Contrast *P* value of positive control versus 35 d value
[5] Contrast *P* value of linear Ractopamine response
[6] Contrast *P* value of quadratic Ractopamine response
[7] Largest observed

Table 3.7. Effect of Ractopamine on boneless cut weights (kg) and weights as a percentage of HCW[1]

	Control						
	NEG[2]	POS[3]	RAC[4]	NEG v. POS[5]	NEG v. RAC[6]	POS v. RAC[7]	Pooled SEM[8]
402F Fresh ham, inside wt, kg	1.55	1.60	1.63	0.372	0.063	0.508	0.065
402F Fresh ham, inside, % of HCW	3.51	3.61	3.59	0.397	0.385	0.787	0.134
402E Fresh ham, outside wt, kg	2.22	2.18	2.32	0.589	0.048	0.007	0.079
402E Fresh ham, outside, % of HCW	5.03	4.93	5.12	0.493	0.376	0.072	0.162
Knuckle wt, kg	1.11	1.20	1.21	0.059	0.005	0.787	0.040
Knuckle, % of HCW	2.51	2.72	2.68	0.058	0.050	0.556	0.086
Lt Butt wt, kg	0.20	0.17	0.21	0.177	0.639	0.023	0.020
Lt Butt, % of HCW	0.45	0.38	0.46	0.154	0.937	0.047	0.041
405A Picnic wt, kg	3.37	3.35	3.50	0.805	0.022	0.009	0.062
405A Picnic, % of HCW	7.64	7.59	7.72	0.705	0.473	0.220	0.116
406 Boston butt wt, kg	3.85	3.40	3.96	0.371	0.004	**< 0.001**	0.048
406 Boston butt, % of HCW	8.72	7.69	8.73	0.296	0.279	0.013	0.099
407 Cellar trimmed butt wt, kg	1.68	1.61	1.70	0.185	0.426	0.010	0.059
407 Cellar trimmed butt, % of HCW	3.80	3.65	3.76	0.142	0.623	0.138	0.124
Clear plate	0.98	0.91	0.86	0.096	**< 0.001**	0.171	0.045
Clear plate, % of HCW	2.22	2.06	1.91	0.070	**< 0.001**	0.030	0.093
414 Canadian back wt, kg	3.10	3.26	3.41	0.081	**< 0.001**	0.028	0.087
414 Canadian back, % of HCW	7.03	7.38	7.53	0.064	0.001	0.309	0.175
415A Tenderloin wt, kg	0.40	0.41	0.45	0.466	**< 0.001**	**< 0.001**	0.014
415A Tenderloin, % of HCW	0.90	0.93	1.00	0.494	**< 0.001**	0.010	0.029
Sirloin wt, kg	0.79	0.85	0.86	0.148	0.024	0.749	0.033
Sirloin, % of HCW	1.79	1.92	1.89	0.144	0.113	0.704	0.070

[1]Wholesale cut weights are indentified by the Institutional Meat Purchase Specification (IMPS, 1996)
[2] Negative control, 13 % CP
[3] Positive control, 17 % CP
[4] Pooled Ractopamine 5.0 ppm and 7.4 ppm data, average of 7, 14, 21, 28, and 35 d durations
[5] Contrast *P* value of negative control versus positive control
[6] Contrast *P* value of negative control versus Ractopamine response averaged across durations
[7] Contrast P value of positive control versus Ractopamine response averaged across durations
[8] Largest observed

Table 3.8. Effect of Ractopamine duration on boneless cut weights (kg) and weights as a percentage of HCW[1]

		Ractopamine[2]								
Duration	POS[3]	7 d	14 d	21 d	28 d	35 d	POS v. 35d[4]	Linear[5]	Quadratic[6]	Pooled SEM[7]
402F Fresh ham, inside wt, kg	1.60	1.55	1.66	1.60	1.63	1.69	0.082	0.010	0.823	0.065
402F Fresh ham, inside, % of HCW	3.61	3.48	3.68	3.56	3.56	3.67	0.606	0.199	0.825	0.134
402E Fresh ham, outside wt, kg	2.18	2.20	2.35	2.33	2.34	2.41	< 0.001	< 0.001	0.361	0.079
402E Fresh ham, outside, % of HCW	4.93	4.94	5.20	5.16	5.10	5.24	0.016	0.034	0.322	0.162
Knuckle wt, kg	1.20	1.18	1.23	1.21	1.23	1.21	0.873	0.449	0.302	0.040
Knuckle, % of HCW	2.72	2.65	2.71	2.68	2.68	2.63	0.339	0.689	0.327	0.086
Lt Butt wt, kg	0.17	0.19	0.21	0.23	0.20	0.20	0.138	0.939	0.033	0.020
Lt Butt, % of HCW	0.38	0.43	0.46	0.52	0.44	0.43	0.241	0.794	0.044	0.041
405A Picnic wt, kg	3.35	3.42	3.49	3.46	3.57	3.56	0.001	0.004	0.899	0.062
405A Picnic, % of HCW	7.59	7.68	7.75	7.68	7.75	7.75	0.209	0.564	0.955	0.116
406 Boston butt wt, kg	3.40	3.52	3.56	3.57	3.68	3.70	< 0.001	< 0.001	0.573	0.048
406 Boston butt, % of HCW	7.69	7.90	7.88	7.92	7.99	8.05	0.003	0.069	0.509	0.099
407 Cellar trimmed butt wt, kg	1.61	1.68	1.66	1.67	1.75	1.76	0.001	0.001	0.238	0.059
407 Cellar trimmed butt, % of HCW	3.65	3.76	3.70	3.71	3.81	3.83	0.045	0.132	0.231	0.124
Clear plate, % of HCW	2.06	2.00	1.91	1.94	1.86	1.82	0.004	0.008	0.983	0.093
414 Canadian back wt, kg	3.26	3.28	3.34	3.36	3.51	3.58	< 0.001	< 0.001	0.370	0.087
414 Canadian back, % of HCW	7.38	7.37	7.39	7.46	7.63	7.79	0.013	< 0.001	0.283	0.175
415A Tenderloin wt, kg	0.41	0.43	0.44	0.44	0.47	0.48	< 0.001	< 0.001	0.930	0.014
415A Tenderloin, % of HCW	0.93	0.96	0.98	0.98	1.03	1.04	0.001	0.001	0.901	0.029
Sirloin wt, kg	0.85	0.80	0.81	0.87	0.90	0.90	0.107	< 0.001	0.653	0.033
Sirloin, % of HCW	1.92	1.80	1.81	1.93	1.96	1.97	0.496	0.001	0.636	0.070

[1]Wholesale cut weights are indentified by the Institutional Meat Purchase Specification (IMPS, 1996)
[2] Pooled Ractopamine 5.0 ppm and 7.4 ppm data
[3] Positive control, 17 % CP, 35 d
[4] Contrast *P* value of positive control versus 35 d value
[5] Contrast *P* value of linear Ractopamine response

[6] Contrast *P* value of quadratic Ractopamine response
[7] Largest observed

Table 3.9. Effect of Ractopamine on loin and fresh ham meat quality

	Control						
	NEG[1]	POS[2]	RAC[3]	NEG v. POS[4]	NEG v. RAC[5]	POS v. RAC[6]	Pooled SEM[7]
Loin							
Ultimate pH	5.60	5.53	5.57	0.091	0.264	0.246	0.032
Minolta L*[8]	47.59	49.66	48.23	0.094	0.499	0.114	1.089
Minolta a*[9]	7.44	7.19	6.81	0.589	0.067	0.266	0.425
Minolta b*[10]	3.99	4.15	3.87	0.749	0.723	0.433	0.442
Color score (NPPC, 1999)[11]	3.0	2.9	2.9	0.643	0.829	0.684	0.076
Marbling score (NPPC, 1999)	3.0	2.7	2.5	0.116	< 0.001	0.185	0.165
Firmness score (NPPC, 1991)[12]	3.0	3.0	2.9	1.000	0.917	0.917	0.120
Japanese Color Score	3.0	2.9	2.9	0.272	0.302	0.657	0.098
Moisture, %	75.04	75.02	75.14	0.890	0.490	0.382	0.145
Extractable lipid, %	2.25	2.13	1.81	0.519	0.002	0.027	0.171
Cook Loss, %	19.85	19.55	19.51	0.655	0.481	0.917	0.567
Shear Force, kg	2.73	2.75	2.83	0.881	0.108	0.160	0.077
Fresh ham							
Ultimate pH	5.68	5.63	5.67	0.317	0.881	0.220	0.038
Minolta L*[8]	47.69	48.18	48.51	0.701	0.404	0.729	0.994
Minolta a*[9]	8.47	8.20	7.52	0.585	0.030	0.125	0.733
Minolta b*[10]	3.52	4.12	3.50	0.275	0.901	0.102	0.457

[1] Negative control, 13 % CP
[2] Positive control, 17 % CP
[3] Pooled Ractopamine 5.0 ppm and 7.4 ppm data, average of 7, 14, 21, 28, and 35 d durations
[4] Contrast *P* value of negative control versus positive control
[5] Contrast *P* value of negative control versus Ractopamine response averaged across durations
[6] Contrast P value of positive control versus Ractopamine response averaged across durations
[7] Largest observed
[8] L*, greater value indicates a lighter color
[9] a*, greater value indicates a redder color
[10] b*, greater value indicates a more yellow color
[11] National Pork Producers Council (NPPC) color scale (1 to 5): 1=pale pinkish to white; 5= dark purplish red.
[12] NPPC firmness scale (1 to 5): 1= very soft; 5= very firm

Table 3.10. Effect of Ractopamine duration on meat quality

		Ractopamine[1]								
Duration	POS[2]	7 d	14 d	21 d	28 d	35 d	POS v. 35d[3]	Linear[4]	Quadratic[5]	Pooled SEM[6]
Loin										
Ultimate pH	5.53	5.54	5.53	5.62	5.54	5.59	0.101	0.169	0.618	0.032
Minolta L*[7]	49.66	49.31	49.32	46.72	47.89	47.80	0.082	**0.025**	0.134	1.089
Minolta a*[8]	7.19	7.33	7.20	6.53	6.53	6.44	0.063	**0.001**	0.411	0.425
Minolta b*[9]	4.15	4.47	4.26	3.30	3.66	3.63	0.226	**0.005**	0.078	0.442
Color score (NPPC, 1999)[10]	2.9	2.8	2.9	3.1	2.9	2.9	0.789	0.200	**0.045**	0.076
Marbling score (NPPC, 1999)	2.7	2.6	2.5	2.4	2.4	2.6	0.544	0.938	0.186	0.165
Firmness score (NPPC, 1991)[11]	3.0	2.9	2.9	2.9	2.9	3.2	0.173	**0.050**	0.137	0.120
Japanese Color Score	2.9	2.8	2.8	3.0	2.9	2.9	0.672	0.293	0.337	0.098
Moisture, %	75.02	75.14	75.06	75.35	74.97	75.19	0.303	0.952	0.824	0.145
Extractable lipid, %	2.13	1.96	2.00	1.70	1.73	1.66	**0.006**	**0.005**	0.743	0.171
Cook Loss, %	19.55	20.27	19.47	19.02	19.41	19.35	0.722	0.076	0.069	0.567
Shear Force, kg	2.75	2.86	2.89	2.75	2.90	2.78	0.669	0.257	0.958	0.077
Fresh ham										
Ultimate pH	5.63	5.65	5.62	5.72	5.67	5.71	0.064	**0.036**	0.800	0.038
Minolta L*[7]	48.18	49.81	49.79	47.77	48.05	47.18	0.373	**0.001**	0.810	0.994
Minolta a*[8]	8.20	8.07	7.46	7.11	7.44	7.38	0.127	0.167	0.137	0.733
Minolta b*[9]	4.12	4.18	3.60	2.95	3.54	3.18	**0.036**	**0.013**	0.090	0.457

[1] Pooled Ractopamine 5.0 ppm and 7.4 ppm data
[2] Positive control, 17 % CP, 35 d
[3] Contrast *P* value of positive control versus 35 d value
[4] Contrast *P* value of linear Ractopamine response
[5] Contrast *P* value of quadratic Ractopamine response
[6] Largest observed
[7] L*, greater value indicates a lighter color
[8] a*, greater value indicates a redder color
[9] b*, greater value indicates a more yellow color
[10] National Pork Producers Council (NPPC) color scale (1 to 5): 1=pale pinkish to white; 5= dark purplish red.
[11] NPPC firmness scale (1 to 5): 1= very soft; 5= very firm

Chapter 4

EFFECTS OF BIRTH WEIGHT ON MUSCLE FIBER NUMBER AND THE EFFECT OF MUSCLE FIBER NUMBER ON GROWTH PERFORMANCE AND MEAT QUALITY IN RESPONSE TO RACTOPAMINE HYDROCHLORIDE (PAYLEAN®)

Abstract

The objective of this study was to investigate the effects of birth weight on muscle fiber number and cross sectional area, and to investigate the effects of muscle fiber number on ractopamine (**RAC**) response, animal performance, carcass traits, and meat quality. This study was divided into two phases: Phase I (growth performance study), 3-weeks post-weaning to 110 kg live weight, and Phase II (RAC feeding period), 110 kg to 134 kg live weight. Phase I was conducted as a randomized complete block design with one treatment (birth weight) at three levels: light (0.9 kg), medium (1.2 kg), and heavy (1.5 kg). From each litter, one pig was selected for each of the weight classifications to create a set. Phase II was conducted as a randomized complete block design with a 3 x 2 factorial arrangement: birth weight classification (light, medium, heavy) and dietary RAC inclusion level (0 and 5 ppm). An additional retrospective analysis was performed where the population was divided in tertiles based on muscle fiber number. Effects from these tertiles were investigated in Phases I and II. Muscle fiber diameter was increased (P = 0.019) by 14.9 μm in the 5 ppm RAC light birth weight classification compared to the 0 ppm RAC light birth weight classification. Differences in other birth weight classifications were not significant ($P > 0.05$). Muscle fiber number was not different

between birth weight classifications (P = 0.353). Correlations demonstrated, with the 0 ppm RAC treatment, as the muscle fiber diameter increased, area increased (r = 0.944) and total number decreased (r = -0.819). As total fiber number increased, muscle fiber area decreased (r = -0.860). Similar trends were also seen in the 5 ppm RAC treatment. No major trends or effects from the fiber number tertiles were seen. Overall, with this population of pigs, light birth weight pigs displayed an increase in muscle fiber diameter in response to RAC, while other muscle fiber characteristics were unaffected by birth weight classification, RAC or fiber number.

Introduction

The piglet's birth weight can have significant effect on its postnatal growth performance. Several studies have demonstrated that low birth weight in piglets correlates with decreased survival and slower postnatal growth rates (Rehfeldt et al., 2000; Milligan et al., 2002; Quiniou et al., 2002; Rehfeldt and Kuhn, 2006). As the piglet matures, it is increasing body weight and muscle mass. Increasing postnatal muscle mass is accomplished through the hypertrophy of existing muscle fibers, as opposed to prenatal muscle growth which is the combination of muscle hypertrophy and hyperplasia. Increases in hyperplasia result in animals with a larger amount of muscle fibers, which result in greater increases in lean tissue accretion (Henckel et al., 1997; Rehfeldt et al., 2000). Wigmore and Stickland (1983) concluded that large porcine fetuses generally had more muscle fiber numbers in their semitendinosus muscle than smaller fetuses. They concluded that most of the variation was due to differences in number of secondary fibers that formed around each primary fiber. In the larger fetuses, the primary fibers were

larger, which would support more secondary fibers, and also the larger fetuses contained more DNA in their muscles. Dwyer et al. (1993) further concluded that on average, growth performance and feed conversion from 25 kg to harvest were positively correlated with muscle fiber number.

Another way to increase postnatal muscle hypertrophy is through the addition of ractopamine hydrochloride (**RAC**). Ractopamine hydrochloride is an orally active β_1-adrenergic agonist that is incorporated into feed rations of finishing swine. Numerous studies have demonstrated the efficacy of RAC in improving ADG, feed efficiency, carcass weight, dressing percentage, and its negligible effects on meat quality (Watkins et al., 1990; Stites et al., 1991; Uttaro et al., 1993; Crome et al., 1996; Carr et al., 2005; Mimbs et al., 2005; Apple et al., 2007; Carr et al., 2009). The objective of this study was to investigate the effects of birth weight on muscle fiber number, cross sectional area, and diameter, and to investigate the effects of muscle fiber number on ractopamine (**RAC**) response, animal performance, carcass traits, and meat quality.

Materials and Methods[1]

Experimental Design and Treatments

This study was divided into two phases: Phase I (growth performance study) was from 3-weeks post-weaning to 110 kg live weight, and Phase II: (RAC feeding period) was from 110 kg to 134 kg live weight. Phase I was conducted as a randomized complete block design with one treatment and three levels: Birth weight classification (Light, Medium, and Heavy). Phase II was conducted as a randomized complete block design

[1] Samples utilized in this study were collected from animals used in a study completed by Chris Puls and the Michal Ellis Lab. The following methods and growth data regarding the live phase of the study are taken from Chris Puls's thesis (2010).

with a 3 x 2 factorial arrangement of the following treatments: 1) Birth weight classification (Light, Medium, and Heavy) and 2) Dietary RAC inclusion level (0 and 5 ppm). There were 24 replicates blocked by room in Phase I of the study, and 12 replicates blocked by room in Phase II of the study. Individual pig was considered the experimental unit in both phases of the study. Birth weight classifications were as follows:

Light (average of 0.9 kg $\pm$ 0.26; range of 0.7 – 1.8 kg)

Medium (average of 1.2 kg $\pm$ 0.27; range of 0.7 – 2.0 kg)

Heavy (average of 1.5 kg $\pm$ 0.27; range of 1.1 – 2.3 kg)

Animals and Allotment

Within 24 h of birth, all piglets (barrows and gilts) were weighed and given a unique identification (ear tag) and barrows were assigned to one of the three birth weight classifications within a litter. Three or six barrows (1 or 2 from each birth weight classification) were identified within each litter. Selected barrows were randomly cross-fostered from within birth weight classification to form litters of a common birth weight classification (i.e. Light, Medium, or Heavy) with an equal number of piglets in each litter. Non-test piglets (remaining barrows and gilts) were cross-fostered onto litters of the same birth weight classification, e.g., heavy non-test piglets were placed in litters of heavy piglets and so on. All piglets were weighed again 24 h prior to weaning (20 $\pm$ 1.9 d of age). Previously selected barrows were chosen for the growth performance study on the basis of birth litter of origin and birth weight classification. Therefore, 3 or 6 littermates were chosen from each birth litter of origin (1 or 2 from each birth weight

classification) so that at least 3 pigs (1 from each birth weight classification) within a common birth litter were allotted to the growth performance study.

Pre-test Management

During farrowing and lactation, sows and piglets were managed according to standard commercial procedures. On approximately d 109 of gestation, sows were moved into farrowing crates that were 1.1 m x 3.1 m (width x length); the farrowing pen was 2.4 m x 3.7 m (width x length). Farrowing pens had plastic coated slotted flooring; the crates were equipped with a feed trough for the sow, and nipple drinkers for both the sow and piglets. The ambient air temperature in the farrowing room was maintained at 22° C throughout lactation using thermostatically controlled fan ventilation and space heaters. During the first week after farrowing, piglets were provided with supplemental heat via a heat lamp suspended approximately 45 cm above the floor on one side of the farrowing crate. At d 4 post-farrowing, piglet processing was carried out and consisted of docking of tails, castration of entire males, and injection of all piglets with 1 ml iron dextran and 0.5 ml of Excede (for the prevention of scours). Prior to farrowing, sows were fed approximately 2.5 kg/d of a corn and soybean meal based lactation diet that was formulated to meet or exceed National Research Council (1998) nutrient requirements. After farrowing, sows were fed approximately 2.5 kg/d until d 3, at which time they were offered ad libitum access to the lactation diet

At weaning, 78 piglets (26 piglets from each birth weight classification) were transported to the University of Illinois using a standard livestock trailer. Pigs were allowed a 3-week acclimation period during which they were housed in groups of 6 or 7 in a mechanically ventilated wean-to-finish facility. The facility consisted of four

identical rooms with fully slotted concrete flooring and pen divisions and gates consisting of vertical steel rods. Each room was 7.32 m long and 8.23 m wide with 2.1 m high ceilings. There were 8 pens per room each measuring 1.83 m x 3.66 m providing a minimum floor space allowance of 0.96 m^2 per pig. Temperature was controlled using thermostatically controlled exhaust fans and a heater in each room. The room temperature was set at 30.5° C for the first week and then gradually lowered until it reached 25° C where it was held for the duration of the acclimation period. Supplemental heat was provided to each pen for the first two weeks post-weaning via a heat lamp suspended 75 cm above two rubber mats, each measuring 60 cm x 60 cm (length x width). Temperature and humidity levels were recorded using HOBO H8 loggers that were programmed to record readings every 12 minutes.

Pigs were offered ad libitum access to feed via a two-hole dry box feeder, and water was freely available via a cup drinker. A standard 2-phase dietary program using corn and soybean meal based diets formulated to meet or exceed the National Research Council (1998) recommendations for nutrient requirements was used. For the first 7 days post-weaning, pigs were provided an additional ~500 g of dry feed on the two rubber mats in each pen twice per day. Diet phases were changed on the basis of pig body weight (Table 1).

Growth Performance Study Management

At the conclusion of the 3-week acclimation period, pigs were moved to an individual housing facility located approximately 40 meters from the acclimation facility where they were housed for the duration of the growth performance study. The facility consisted of two identical rooms with fully slotted plastic flooring and pen divisions and

gates consisted of vertical steel rods. Each room was 18.0 m long and 4.6 m wide with 2.1 m high ceilings and a central 0.6 m wide aisle. There were 36 pens in each room measuring 1.0 m x 2.0 m, providing a floor space allowance of 2.0 m^2 per pig. Temperature was regulated by thermostatically controlled fans and a heater suspended in each room. The room temperature was set at 25° C for the first week and then gradually lowered until it reached 19° C where it was held for the duration of the study period. Temperature and humidity levels were recorded using HOBO H8 loggers that were programmed to record readings every 12 minutes.

During Phase I of the study (3 weeks post-weaning to 110 kg live weight), a 5-phase dietary program was used with diets being based on corn and soybean meal and formulated to meet or exceed the National Research Council (1998) recommendations for nutrient requirements. Pigs were offered ad libitum access to feed via a single space stainless steel dry box feeder mounted to the front gate of each pen and water was freely available via a cup drinker mounted on the pen partition 30 cm from the back of the pen. Diet phases were changed on the basis of pig body weight (Table 4.1).

Ractopamine Feeding Period Management

Phase II of the study period (RAC feeding period) was carried out between 110 kg and 134 kg live weight. Pigs were housed in the same facility and managed similarly to Phase I. A single phase corn and soybean meal based diet containing either 0 or 5 ppm RAC inclusion was used throughout this period. This diet was formulated to meet or exceed the National Research Council (1998) recommendations for nutrient requirements for finishing pigs with the exception that protein and lysine levels were set to meet the requirement of pigs fed RAC at 5 ppm (Table 4.2). Pigs were offered ad libitum access

to feed and water was freely available via a cup drinker throughout the RAC feeding period.

Growth Measurements

Phase I of the study was carried out from the end of week 3 post-weaning to 110 kg live weight. During Phase I, pigs were individually weighed every two weeks until they reached 110 kg live weight. All feed additions and feed remaining in the feeder at the time of pig weighing were measured to determine feed intake and gain:feed ratio.

Phase II (RAC feeding period) of the study was carried out from 110 kg live weight to 134 kg live weight. During Phase II, pigs were individually weighed once per week until they reached 134 kg live weight. All feed additions and feed remaining in the feeder at the time of pig weighing were measured to determine feed intake and gain:feed ratio. At 134 kg live weight, pigs were removed from test and transported to the University of Illinois Meat Sciences Laboratory (MSL) for harvest.

Carcass and Meat Quality Measurements

Day of harvest, pigs were electrically stunned, exsanguinated, scalded, dehaired, decapitated, eviscerated, split, inspected, and placed immediately into a 4°C chill cooler. Approximate time from stun to cooler was 45 min, where the 45 min pH was recorded. After chilling for approximately 20 h, first rib, last rib, last rib, last lumbar vertebra back fat depths, and carcass length were recorded. After which, the left side was ribbed at the 10^{th} rib and allowed to bloom for approximately 15 min. Last-rib, 10th-rib fat depths, and 10^{th}-rib loin eye area (**LEA**) were measured. Loin eye area was measured with an acetate paper tracing, from which an area was measured using an area line meter (Super PLANIX α Polar Planimeter; Tokyo, Japan). Meat quality traits measured at the 10^{th} rib

included subjective color and marbling scores (NPPC, 1999), subjective firmness (NPPC, 1991), and objective color utilizing a Minolta CR-300 with a D65 light source and a 0° observer (Minolta Camera Company, Osaka, Japan). A section of longissimus was dissected out posterior to the 10th rib, faced off and chops were cut. Chop collection starting from the tenth rib included: 1.3 cm thick chop for drip loss; 2.54 cm thick chop for proximate composition analysis; and 2.54 cm thick chop aged for 14 d for Warner Bratzler shear force determination. After 14 d, chops were frozen until d of analysis, whereupon they were thawed and trimmed to a uniform size and cooked on a Farberware Open Hearth grill (Model 455 N, Walter Kidde, Bronx, NY). Chops were weighed, cooked on one side to an internal temperature of 35° C, turned over and cooked to a final internal temperature of 70° C, and reweighed to calculate percent cooking loss. During cooking, internal temperature was monitored using copper-constantan thermocouples (Type T, Omega Engineering, Stanford, CT) connected to a digital scanning thermometer (Model 92000-00, Barnart Co., Barington, IL). Chops were allowed to cool and four cores (1.3 cm) were removed parallel to the orientation of the muscle fibers. Cores were sheared using a Texture Analyzer TA.HD Plus (Texture Technologies Corp., Scarsdale, NY; Stable Microsystems, Godalming, UK) with a blade speed of 200 mm/min and a load cell capacity of 980.4 N (100 kg). Shear force was determined for each core, and these values were averaged for each sample. Drip loss was used to evaluate water-holding capacity. Drip loss chops were weighed, suspended from a fish hook in a Whirl-pak bag for approximately 24 h at 4 °C and then reweighed. Results were reported on a percent loss basis. Proximate composition on homogenized samples was determined with oven drying to determine moisture content, and extraction with an azeotropic chloroform

and methanol mixture to determine extractable lipid, as described by (Novakofski et al., 1989).

Fat free lean was measured by performing a carcass soft tissue dissection. The right side of the carcass was dissected into skin, bone, and soft tissue components. Each component was weighed, and the soft tissue was ground through a Hobart Model 4152 Grinder (Hobart Corporation, Troy, OH) and 12 representative sub-samples were taken from the ground mixture and these were homogenized in a Talsa Model C40P Bowl Chopper (Stancase Equipment Company, Jersey City, NJ). Two 500 g samples were taken and frozen for subsequent proximate analysis as detailed previously for loin proximate analysis.

Histology

Approximately 24 hours post harvest, after LEA was recorded, a sample was removed from the 10^{th} rib face and prepared for histology. A section perpendicular to the muscle fiber orientation was fixed in 10 % formalin for 72 hr. After which the sample was paraffin embedded, sectioned and stained with hematoxylin and eosin stain at the University of Illinois Veterinary Pathology Laboratory. Images were captured at 5 X power and approximately 500 fibers per animal were measured using Image J software (version 1.42, National Institute of Health). Muscle fiber feret-diameter and fiber area were recorded. Total fiber number was calculated by dividing the LEA by the fiber area.

Statistical Analysis

Data were analyzed using the PROC MIXED procedure of SAS (2000). Least-squares means were compared using the PDIFF and STDERR options of SAS. Differences of muscle fiber characteristics between birth weight classifications and RAC

were analyzed as a randomized complete block design with 2 treatments (birth weight classification and RAC inclusion level). The model included the fixed effects of birth weight classification and RAC inclusion level, and the two-way interaction, and random effects of room and replicate nested within room. Individual pig was the experimental unit.

A subsequent analysis was performed where pigs were broken into tertiles based on their total muscle fiber number (fiber number classification) at harvest, regardless of birth weight. Data were analyzed utilizing PROC MIXED (SAS Inst. Inc., 2000). For Phase I, model included the fixed effect of fiber number classification, and random effects of room and replicate nested within room. Phase II, model included the fixed effects of fiber number classification, ractopamine inclusion and the two-way interaction, and random effects of room and replicate nested within room. Individual pig was the experimental unit.

Correlations were analyzed with the PROC CORR procedure of SAS (2000). Correlation results are presented in the appendix.

Results and Discussion

Effects of birth weight classification and RAC on muscle fiber characteristics are listed in Table 4.3. Birth weights were broken into three classifications: light (0.9 kg), medium (1.2 kg), and heavy (1.5 kg), with significant differences (P = 0.001) between each classification. Muscle fiber diameter was increased (P = 0.019) 14.9 um in the 5 ppm RAC light birth weight classification compared to the 0 ppm RAC light birth weight classification. Differences in other birth weight classifications were not significant (P >

0.05). Muscle fiber number was not different between birth weight classifications (P = 0.353). Other studies have demonstrated differences in muscle fiber number in relation in birth weight. Wigmore and Stickland (1983) concluded that large porcine fetuses generally had more muscle fiber numbers in their semitendinosus muscle than smaller fetuses. At 64 days' gestation there was a 17 % difference in total muscle (semitendionous) number in light versus heavy birth weight. They concluded that most of the total number variation was due to differences in number of secondary fibers that formed around each primary fiber. In the larger fetuses, the primary fibers were larger, which would support more secondary fibers, and also the larger fetuses contained more DNA in their muscles. In a similar study, Rehfeldt and Kuhn (2006) found differences in total fetal semitendosus number of muscle fibers (275,000 vs 325,000) between low birth weight groups (< 1.20 kg) and heavy birth weight groups (> 1.62 kg). In this study RAC had no effect (P = 0.852) on number of muscle fibers. This is in agreement with the literature, as postnatal hyperplasia (increase in muscle fibers) is nonexistent (Rehfeldt et al., 2000).

Correlation coefficients between muscle fiber area, diameter, and total number are presented in Table 4.4. Correlations between all three characteristics were highly significant (P < 0.001). With the 0 ppm RAC treatment, as the muscle fiber diameter increased, area increased (r = 0.944) and total number decreased (r = -0.819). As total number increased, muscle area decreased (r = -0.860). Similar correlations were also seen in the 5 ppm RAC treatment. Larzul et al. (1997) saw similar trends with r = -0.79 between total fiber number and fiber area. One would expect a high correlation however, as the fiber area is used to calculate total fiber number.

Least square means for fiber number classifications are presented in Table 4.5. Fiber number increased ($P < 0.05$) from 1.3 million (low classification), to 1.7 million (medium classification), to 2.1 million (high classification). Fiber area decreased ($P < 0.05$) as fiber number classification increased, 3481.7 µm (low), 2791.6 µm (medium), and 2253.1 µm (high). Gondret et al. (2006) saw similar trends with increases in muscle fiber area as total muscle number decreased.

Least square means for effects of fiber number classification on the growth performance of pigs from birth to 110 kg live weight (Phase I) are presented in table 4.6. Fiber number classification did not have an effect on any of the growth performance measurements from birth to 110 kg, except for ADFI which was decreased ($P = 0.027$) in the medium versus the low fiber number classification during the last two weeks of phase I.

Least square means for the effects of fiber number classification and ractopamine inclusion level on growth performance from 110 kg to 134 kg body weight (Phase II) are presented in Table 4.7. Least square means from RAC inclusion will not be discussed unless there was an interaction with the fiber number classification. A discussion on the RAC results can be found in Puls (2010). The low fiber number classification had 2.6 more ($P = 0.012$) days on test compared to the high fiber number classification. Previous literature has also demonstrated that pigs with greater fiber numbers reached final weight quicker (Rehfeldt et al., 2000; Rehfeldt and Kuhn, 2006).

Least square means for the effects of fiber number classification and ractopamine inclusion level on carcass characteristics from 110 kg to 134 kg body weight (Phase II) are presented in Table 4.8. There was an interaction between fiber number classification

and RAC with HCW. The pigs from the low fiber number classification did not respond to RAC, while the medium and high fiber number classification increased ($P < 0.05$) HCW weight approximately 4 kg.

Least square means for the effects of fiber number classification and ractopamine inclusion level on Longissimus meat quality (Phase II) are presented in Table 4.9. Ultimate pH was approximately 0.08 units higher in the low fiber number compared to both the medium and high fiber number classification. Percent moisture in the loin was decreased to 73 .79 % in the low fiber number classification compared to 74.43 % in the medium fiber number classification.

Implications

Overall, with this population of pigs, light birth weight pigs displayed an increase in muscle fiber diameter in response to RAC, while other muscle fiber characteristics were unaffected by birth weight classification, RAC or fiber number.

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Tables

Table 4.1. Dietary phases, composition, and calculated analysis (as-fed basis) from 6 to 110 kg BW.

	Dietary phase						
Item	Nursery 1	Nursery 2	Nursery 3	Grower 1	Grower 2	Finisher 1	Finisher 2
BW range, kg	6-8	8-11	11-23	23-45	34-68	68-90	90-110
Ingredient, %							
Corn	43.39	51.38	61.02	62.51	70.50	74.62	78.60
Dehulled soybean meal	22.28	27.52	32.43	31.86	23.91	19.92	15.95
Spray-dried plasma	2.50	0.00	0.00	0.00	0.00	0.00	0.00
Select Menhaden fish meal	5.00	3.75	0.00	0.00	0.00	0.00	0.00
Spray dried whey	10.00	5.00	0.00	0.00	0.00	0.00	0.00
Lactose	10.00	5.00	0.00	0.00	0.00	0.00	0.00
Choice white grease	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Mono-calcium Phosphate, 21% P	0.25	0.75	1.15	0.85	0.85	0.80	0.80
Limestone	0.75	0.75	0.95	0.85	0.85	0.80	0.80
Salt	0.30	0.30	0.50	0.50	0.50	0.50	0.50
Zinc oxide	0.30	0.30	0.00	0.00	0.00	0.00	0.00
Vitamin premix	0.05	0.05	0.05	0.03	0.03	0.03	0.03
Trace mineral premix	0.10	0.10	0.10	0.10	0.09	0.09	0.08
Lysine HCl	0.23	0.28	0.38	0.20	0.20	0.20	0.20
DL-Methionine	0.15	0.18	0.15	0.05	0.03	0.00	0.00
L-Threonine	0.11	0.15	0.15	0.05	0.05	0.05	0.05
Carbadox	0.25	0.25	0.13	0.00	0.00	0.00	0.00
Spray-dried blood cells	1.25	1.25	0.00	0.00	0.00	0.00	0.00
Calculated analysis							
Crude protein, %	22.40	22.00	20.80	20.39	17.35	15.83	14.32
Total ileal digestible lysine, %	1.45	1.40	1.30	1.15	0.95	0.85	0.75

Ca, %	0.81	0.79	0.70	0.61	0.58	0.54	0.53
P, %	0.66	0.68	0.64	0.57	0.54	0.51	0.50
ME, kcal/kg	3,453	3,441	3,452	3,467	3,470	3,475	3,477

Table 4.2. Dietary phases, composition, and calculated analysis (as-fed basis) from 110 to 134 kg BW.

	Dietary phase	
Item	No Ractopamine	Ractopamine
Ingredient, %		
Corn	70.75	70.73
Dehulled soybean meal	23.89	23.89
Choice white grease	3.00	3.00
Mono-calcium Phosphate, 21% P	0.75	0.75
Limestone	0.75	0.75
Salt	0.50	0.50
Vitamin premix	0.03	0.03
Trace mineral premix	0.08	0.08
Lysine HCl	0.20	0.02
L-Threonine	0.06	0.06
Ractopamine	0.00	0.03
Calculated analysis		
Crude protein, %	17.40	17.40
Total ileal digestible lysine, %	0.95	0.95
Ca, %	0.53	0.53
P, %	0.52	0.52
ME, kcal/kg	3,476	3,476

Table 4.3. Least square means for the effect of birth weight on muscle fiber characteristics

	Birth weight classification				Ractopamine			*P*-value		
Item	Light	Medium	Heavy	SEM	0 ppm	5 ppm	SEM	Birth weight	Ractopamine	Birth weight x Ractopamine
Number of pigs	23	24	24	-	35	36				
Birth weight, kg	0.9[a]	1.2[b]	1.5[c]	0.05	-	-		0.001	-	-
Muscle fiber diameter, um	-	-	-	3.08	-	-	-	0.838	0.257	0.099
Ractopamine										
0 ppm	108.2[b]	113.3[ab]	114.9[ab]							
5 ppm	123.1[a]	113.6[ab]	111.8[ab]							
Muscle fiber area, um^2	2856.7	2854.5	2833.9	142.7	2762.4	2929.7	118.5	0.995	0.305	0.134
Muscle fiber number, millions	1.661	1.672	1.819	0.086	1.731	1.712	0.073	0.353	0.852	0.366

[a,b] Means within a row with differing superscripts are significantly different ($P < 0.05$)

Table 4.4. Correlation coefficients between muscle fiber characteristics

	Ractopamine					
	0 ppm			5 ppm		
Muscle Fiber Characteristic	Diameter	Area	Number	Diameter	Area	Number
Diameter	-	0.944†	-0.819†	-	0.956†	-0.840†
Area	-	-	-0.860†	-	-	-0.861†
Number	-	-	-	-	-	-

†$P < 0.001$

Table 4.5. Least square means for the effect of muscle fiber number on muscle fiber characteristics

	Fiber number classification				
Item	Low	Medium	High	SEM	*P*-value
Number of pigs	24	24	24		
Fiber number, x1000	1315[a]	1732[b]	2131[c]	42	<.0001
fiber area, um2	3481.7[c]	2791.6[b]	2253.1[a]	132.03	<.0001
Fiber diameter, um	128.1[c]	113.1[b]	100.9[a]	2.92	<.0001

Table 4.6. Least square means for the effect of fiber number on the growth performance of pigs to 110 kg live weight (Phase I).

	Fiber number classification				
Item	Low	Medium	High	SEM	*P*-value
Number of pigs	24	24	24		
Body weight, kg					
Birth	1.2	1.2	1.3	0.08	0.650
Week 3 post-weaning	13.6	14.2	13.3	1.10	0.520
Week 5 post-weaning	23.8	24.6	23.2	1.72	0.500
Week 6 post-weaning	29.0	30.0	28.7	2.04	0.595
Week 8 post-weaning	43.4	44.5	43.6	2.15	0.732
Week 10 post-weaning	57.7	59.0	57.9	2.13	0.745
Week 12 post-weaning[1]	73.6	74.7	73.4	2.53	0.808
End (~110 kg live weight)[2]	110.9	110.9	111.3	0.45	0.803
Days on test	94.3	94.9	95.7	1.69	0.771
Average daily gain, kg					
Week 3 - 5 post-weaning	0.68	0.70	0.66	0.04	0.604
Week 5 - 6 post-weaning	0.75	0.77	0.77	0.05	0.931
Week 6 - 8 post-weaning	1.01	1.05	1.06	0.03	0.429
Week 8 - 10 post-weaning	0.49	0.48	0.48	0.02	0.688
Week 10 - 12 post-weaning	1.14	1.12	1.10	0.03	0.662
Week 12 - End[3]	1.25	1.18	1.20	0.03	0.140
Week 3 - End	1.04	1.02	1.02	0.01	0.713
Average daily feed intake, kg					
Week 3 - 5 post-weaning	1.01	0.95	0.99	0.13	0.856
Week 5 - 6 post-weaning	1.40	1.33	1.21	0.09	0.292
Week 6 - 8 post-weaning	1.69	1.74	1.72	0.06	0.682
Week 8 - 10 post-weaning	2.11	2.15	2.15	0.07	0.842
Week 10 - 12 post-weaning	2.56	2.52	2.52	0.09	0.815
Week 12 - End[3]	3.11[a]	2.91[b]	3.02[ab]	0.05	0.027
Week 3 - End	2.33	2.23	2.30	0.05	0.148
Gain:feed, kg:kg					
Week 3 - 5 post-weaning	0.736	0.747	0.720	0.078	0.798
Week 5 - 6 post-weaning	0.585	0.642	0.578	0.029	0.221
Week 6 - 8 post-weaning	0.601	0.611	0.619	0.020	0.651
Week 8 - 10 post-weaning	0.493	0.483	0.478	0.019	0.688
Week 10 - 12 post-weaning	0.445	0.447	0.438	0.012	0.810
Week 12 - End[3]	0.399	0.406	0.398	0.009	0.682
Week 3 - End	0.446	0.459	0.447	0.007	0.149

[a,b,c]Means within a row with differing superscripts are significantly different ($P < 0.05$)
[1]Some pigs began the Paylean feeding period at week 12 post-weaning.
[2]All pigs ended the birth weight growth performance period at ~110 kg live weight.
[3]Calculations are from week 12 post-weaning to 110 kg live weight.

Table 4.7. Least square means for the effect of fiber number and ractopamine inclusion level on the growth performance from 110 kg to 134 kg BW (Phase II).

	Fiber number classification				Ractopamine			*P*-values		
Item	Low	Medium	High	SEM	0 ppm	5 ppm	SEM	FNC	Paylean	FNC x Paylean
Number of pigs	23	24	24	-	35	36	-	-	-	-
Body weight, kg										
Start (~110 kg live weight)	110.9	110.9	111.3	0.46	110.9	110.9	0.33	0.806	0.960	0.830
Week 1	117.5	116.2	118.0	0.85	116.7	118.1	0.64	0.318	0.140	0.911
Week 2	125.1	123.3	125.3	0.71	123.1[b]	126.3[a]	0.55	0.111	0.001	0.951
End (~134 kg live weight)[1]	135.4	134.0	133.8	0.67	133.4[b]	135.3[a]	0.53	0.177	0.010	0.281
Days on test	21.9[a]	20.6[ab]	19.3[b]	0.04	22.0[b]	19.3[a]	0.63	0.040	0.001	0.393
Average daily gain, kg										
Start - Week 1	1.09	1.26	1.13	0.10	1.06[b]	1.31[a]	0.07	0.423	0.020	0.569
Week 1 – 2	1.10	1.03	1.09	0.09	0.95[b]	1.17[a]	0.06	0.790	0.010	0.897
Week 2 - End	1.28	1.26	1.41	0.10	1.18[b]	1.43[a]	0.08	0.492	0.020	0.668
Start - End	1.15	1.14	1.17	0.04	1.06[b]	1.25[a]	0.03	0.810	0.001	0.657
Average daily feed intake, kg										
Start - Week 1	3.14	2.96	3.13	0.11	3.19	3.08	0.09	0.335	0.310	0.467
Week 1 - 2	3.10	3.03	3.00	0.10	3.06	3.02	0.07	0.720	0.630	0.965
Week 2 - End	3.48	3.31	3.53	0.10	3.41	3.48	0.08	0.247	0.520	0.937
Start - End	3.52	3.41	3.52	0.06	3.52	3.51	0.06	0.260	0.680	0.239
Gain:feed, kg:kg										
Start - Week 1	0.338	0.396	0.398	0.026	0.337[b]	0.417[a]	0.019	0.160	0.004	0.716
Week 1 - 2	0.360	0.348	0.371	0.038	0.325[b]	0.388[a]	0.030	0.728	0.010	0.935
Week 2 - End	0.365	0.376	0.390	0.021	0.343[b]	0.404[a]	0.017	0.632	0.004	0.279
Start - End	0.327	0.332	0.334	0.009	0.300[b]	0.358[a]	0.007	0.839	0.001	0.864

[a,b]Means within a row with differing superscripts are significantly different ($P < 0.05$).

[1]Pigs were sent for harvest at a fixed target weight of 134 $\pm$ 3 kg live weight.

Table 4.8. Least square means for the effect of fiber number and ractopamine inclusion level on carcass characteristics of pigs

	Fiber number classification				Ractopamine			*P*-values		
Item	Low	Medium	High	SEM	0 ppm	5 ppm	SEM	FNC	Paylean	FNC x Paylean
Number of pigs	23	24	24	-	35	36	-	-	-	-
Hot carcass weight, kg	-	-	-	0.4883			0.2	0.3564	0.04	0.0069
Ratopamine										
0 ppm	100.1[b]	97.2[a]	97.4[a]							
5 ppm	99.7[b]	101.2[b]	100.4[b]							
Dressing percentage	76.85	76.76	76.78	0.19	76.52[a]	77.04[b]	0.16	0.936	0.044	0.505
Fat-free lean, %[1]	58.46	59.97	59.15	0.51	58.67[a]	59.71[b]	0.40	0.104	0.050	0.729
Loin eye area, cm^2	44.75[a]	47.76[b]	48.78[b]	1.15	46.00	47.55	2.581	0.012	0.162	0.407
Backfat thickness, cm										
First rib	1.87	1.93	1.97	0.07	1.94	1.89	0.05	0.410	0.440	0.281
Tenth rib	1.03	0.99	0.97	0.04	1.02	1.05	0.044	0.574	0.510	0.412
Last rib	0.98	1.00	1.03	0.05	0.99	1.01	0.044	0.739	0.721	0.880
Last lumbar vertebra	0.88	0.87	0.86	0.03	0.82	0.88	0.027	0.806	0.110	0.694
Carcass length, cm	89.38	88.58	88.20	0.19	89.04	88.40	0.185	0.108	0.132	0.599

[a,b,c]Means within a row with differing superscripts are significantly different ($P < 0.05$)

[1]Actual dissected value

Table 4.9. Least square means for the effect of fiber number and ractopamine inclusion level on Longissimus muscle meat quality

	Fiber number classification				Ractopamine			*P*-values		
Item	Low	Medium	High	SEM	0 ppm	5 ppm	SEM	FNC	Paylean	FNC x Paylean
Number of pigs	23	24	24	-	35	36	-	-	-	-
Color score (NPPC, 1999)[1]	2.5	2.5	2.4	0.1	2.4	2.4	0.15	0.781	0.960	0.176
Marbling (NPPC, 1999)[2]	2.0	1.6	1.7	0.2	1.7	1.9	0.23	0.138	0.401	0.104
Firmness (NPPC, 1991)[3]	2.8	2.7	2.6	0.2	2.4	2.7	0.18	0.620	0.080	0.734
pH 45	6.14	6.02	6.04	0.06	5.98[a]	6.14[b]	0.06	0.310	0.030	0.186
Ultimate pH	5.55[b]	5.48[a]	5.46[a]	0.02	5.46	5.48	0.02	0.001	0.314	0.454
Minolta L*[4]	50.52	51.43	52.82	0.99	53.46	52.61	0.89	0.232	0.384	0.700
Minolta a*[5]	8.03	8.57	8.41	0.51	9.06	8.54	0.43	0.598	0.230	0.152
Minolta b*[6]	4.84	5.45	5.80	0.44	5.94	5.46	0.38	0.193	0.263	0.139
Drip loss, %	5.23	4.95	3.60	0.54	5.09	4.35	0.54	0.082	0.260	0.247
Shear force, kg	3.00	3.22	3.15	0.21	3.13	3.27	0.21	0.413	0.304	0.587
Proximate analysis, %										
Moisture	73.79[a]	74.43[b]	74.06[ab]	0.27	74.19	73.83	0.22	0.013	0.092	0.224
Fat	2.83	2.28	2.40	0.38	2.17[a]	2.60[b]	0.32	0.108	0.031	0.206

[a,b,c]Means within a row with differing superscripts are significantly different ($P < 0.05$)

[1] National Pork Producers Council (NPPC) color scale (1 to 5): 1=pale pinkish to white; 5= dark purplish red.

[2] NPPC marbling scale (1 to 5): percentage fat in the loin.

[3] NPPC firmness scale (1 to 5): 1= very soft; 5= very firm.

[4] L*, greater value indicates a lighter color.

[5] a*, greater value indicates a redder color.

[6] b*, greater value indicates a more yellow color.

Appendix

Table A.1. Correlation coefficients of muscle fiber characteristics to growth performance from birth to 110 kg live weight (Phase I)

	Muscle fiber characteristics		
Item	Diameter	Area	Number
Number of pigs	71	71	71
Body weight, kg			
Birth	-0.034	-0.003	0.219
Week 3 post-weaning	0.072	0.140	-0.031
Week 5 post-weaning	0.044	0.122	-0.003
Week 6 post-weaning	0.034	0.104	-0.007
Week 8 post-weaning	-0.041	0.035	0.030
Week 10 post-weaning	-0.039	0.031	0.082
Week 12 post-weaning[1]	-0.027	0.049	0.050
End (~110 kg live weight)[2]	-0.124	-0.152	0.155
Days on test	-0.048	-0.115	0.018
Average daily gain, kg			
Week 3 - 5 post-weaning	-0.010	0.075	0.046
Week 5 - 6 post-weaning	-0.030	-0.033	-0.019
Week 6 - 8 post-weaning	-0.241	-0.197	0.124
Week 8 - 10 post-weaning	0.156	0.110	0.034
Week 10 - 12 post-weaning	0.028	0.083	-0.083
Week 12 - End[3]	0.141	0.113	-0.078
Week 3 - End	0.003	0.038	0.028
Average daily feed intake, kg			
Week 3 - 5 post-weaning	0.047	0.125	-0.041
Week 5 - 6 post-weaning	0.097	0.155	-0.084
Week 6 - 8 post-weaning	-0.168	-0.112	0.048
Week 8 - 10 post-weaning	-0.135	-0.072	0.158
Week 10 - 12 post-weaning	0.062	0.117	-0.040
Week 12 - End[3]	0.199	0.255$^{\lozenge}$	-0.175
Week 3 - End	0.100	0.156	-0.080
Gain:feed, kg:kg			
Week 3 - 5 post-weaning	0.021	-0.012	0.032
Week 5 - 6 post-weaning	-0.041	-0.094	-0.001
Week 6 - 8 post-weaning	-0.063	-0.077	0.074
Week 8 - 10 post-weaning	0.156	0.110	0.034
Week 10 - 12 post-weaning	-0.030	-0.018	-0.059
Week 12 - End[3]	-0.015	-0.110	0.070
Week 3 - End	-0.121	-0.156	0.131

[1]Some pigs began the Paylean feeding period at week 12 post-weaning.
[2]All pigs ended the birth weight growth performance period at ~110 kg live weight
[3]Calculations are from week 12 post-weaning to 110 kg live weight.
$^{\lozenge}P < 0.05$

Table A.2. Correlation coefficients of muscle fiber characteristics to growth performance during the ractopamine finishing phase (110 kg to 134 kg, Phase II)

	Ractopamine					
	0 ppm			5 ppm		
	Muscle Fiber Characteristic			Muscle Fiber Characteristic		
Item	Diameter	Area	Number	Diameter	Area	Number
Number of pigs	71	71	71	71	71	71
Body weight, kg						
Start (~110 kg live weight)	0.027	-0.001	0.037	-0.297	-0.334*	0.315
Week 1	0.030	0.070	0.115	-0.109	-0.072	0.173
Week 2	0.057	0.198	0.033	-0.054	0.010	0.044
End (~134 kg live weight)[1]	0.513◊	0.597◊	-0.473◊	0.134	0.124	-0.002
Days on test	0.341◊	0.289*	-0.442◊	0.332*	0.313	-0.145
Average daily gain						
Start - Week 1	-0.057	0.031	0.076	-0.055	-0.062	0.007
Week 1 - 2	-0.085	0.039	-0.109	0.086	0.115	-0.189
Week 2 - End	0.015	0.014	0.193	-0.202	-0.177	0.181
Start - End	-0.049	0.063	0.193	-0.071	-0.036	-0.015
Average daily feed intake						
Start - Week 1	-0.131	-0.086	0.202	-0.061	-0.080	-0.073
Week 1 - 2	0.051	0.186	-0.153	0.081	0.124	-0.211
Week 2 - End	-0.044	0.023	0.124	-0.127	-0.091	0.024
Start - End	-0.155	-0.041	0.131	-0.046	-0.040	-0.147
Gain:feed						
Start - Week 1	-0.242	-0.163	0.395◊	-0.205	-0.139	0.151
Week 1 - 2	-0.174	-0.095	0.047	0.038	0.048	-0.094
Week 2 - End	0.119	0.069	0.114	-0.225	-0.211	0.240
Start - End	0.044	0.124	0.135	-0.061	-0.017	0.071

*$P < 0.10$

◊$P < 0.05$

[1]Pigs were sent for harvest at a fixed target weight of 134 $\pm$ 3 kg live weight.

Table A.3. Correlation coefficients of muscle fiber characteristics to carcass characteristics

	Ractopamine					
	0 ppm			5 ppm		
	Muscle Fiber Characteristic			Muscle Fiber Characteristic		
	Diameter	Area	Number	Diameter	Area	Number
Number of pigs	71	71	71	71	71	71
Harvest live weight	0.559$^{\lozenge}$	0.652$^{\lozenge}$	-0.491$^{\lozenge}$	-0.161	-0.172	0.194
Hot carcass weight	0.588$^{\lozenge}$	0.610$^{\lozenge}$	-0.492$^{\lozenge}$	-0.020	-0.078	0.172
Dressing percentage	0.241	0.116	-0.159	0.164	0.074	0.025
Fat free lean	-0.173	-0.236	0.377$^{\lozenge}$	-0.020	-0.084	0.156
Loin eye area	0.040	-0.037	0.459$^{\lozenge}$	-0.035	-0.002	0.452$^{\lozenge}$
Backfat thickness						
First rib	-0.378$^{\lozenge}$	-0.391$^{\lozenge}$	0.260	-0.218	-0.274	0.026
Tenth rib	-0.260	-0.241	-0.011	0.260	0.262	-0.437$^{\lozenge}$
Last rib	-0.132	-0.221	0.206	0.090	0.108	0.077
Last lumbar	-0.152	-0.183	0.007	0.281	0.229	-0.284
Carcass length	0.229	0.299*	-0.316*	0.006	0.082	-0.121

$^{*}P < 0.10$

$^{\lozenge}P < 0.05$

Table A.4. Correlation coefficients of muscle fiber characteristics to Longissimus meat quality

	Ractopamine					
	0 ppm			5 ppm		
	Muscle Fiber Characteristic			Muscle Fiber Characteristic		
Item	Diameter	Area	Number	Diameter	Area	Number
Number of pigs	71	71	71	71	71	71
Color score (NPPC, 1999)	0.086	0.119	-0.145	-0.154	-0.054	0.071
Marbling (NPPC, 1999)	-0.340	-0.266	0.053	0.575$^{\lozenge}$	0.613$^{\lozenge}$	-0.619$^{\lozenge}$
Firmness (NPPC, 1991)	-0.048	0.008	-0.151	0.199	0.278	-0.371$^{\lozenge}$
pH, 45 min postmortem	0.030	0.063	0.070	0.228	0.256	-0.266
Ultimate pH	0.405$^{\lozenge}$	0.440$^{\lozenge}$	-0.434$^{\lozenge}$	0.407$^{\lozenge}$	0.430$^{\lozenge}$	-0.514$^{\lozenge}$
Minolta L*	-0.123	-0.153	0.128	-0.101	-0.150	0.215
Minolta a*	0.079	0.023	-0.132	-0.248	-0.270	0.329*
Minolta b*	-0.034	-0.100	0.013	-0.209	-0.245	0.349*
Drip loss	0.024	-0.056	0.104	-0.470$^{\lozenge}$	-0.526$^{\lozenge}$	0.535$^{\lozenge}$
Cook loss	-0.290	-0.305*	0.309*	-0.378$^{\lozenge}$	0.360*	0.343*
Shear force	0.058	0.018	-0.020	-0.374$^{\lozenge}$	0.410$^{\lozenge}$	0.367*
Proximate analysis						
Moisture	0.245	0.252	-0.074	-0.428$^{\lozenge}$	0.467$^{\lozenge}$	0.463$^{\lozenge}$
Extractable lipid	-0.308*	-0.341*	0.054	0.454$^{\lozenge}$	0.505$^{\lozenge}$	-0.498$^{\lozenge}$

$^{*}P < 0.10$
$^{\lozenge}P < 0.05$

AUTHOR'S BIOGRAPHY

Louis W. Kutzler, born December 12th, 1979, is the oldest child of Louis and Janel Kutzler of Chatham, Illinois. He has one sister, Adriene. Lou earned an A.S. degree in Biology from Lincoln Land Community College in 2000. He transferred to the University of Illinois at Urbana-Champaign where he earned a B.S. in Animal Science in 2002, M.S. in Animal Science in 2006, and Ph.D. in Animal Science in 2010. Lou married Allison L. Czmarko of St. Louis, Missouri, on April 17th, 2003.